COMPUTER AIDED DESIGN OF FREE STANDING STEEL TOWERS

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CERTIFICATE

It is certified That this work " COMPUTER AIDED DESIGN OF FREE STANDING STEEL TOWERS" by Pawan R. Gupta has been carried out under my supervision and that this work has not been submitted for a degree elsewhere.

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ABSTRACT

In the present work Computer Aided Analysis and Design of Free Standing Steel Towers are considered. Since huge inputs are required to define the geometry of the tower, a preprocessor is developed which is very versatile and is capable of generating the geometry of the commonly used towers easily with minimum input data. To enable the small computers to solve reasonably large problems the program was devised to use the minimum core memory possible. This required an extensive network of unformatted disk files, although this increased the total elapsed somewhat due to reading and writing operations, but the total c.p.u time was about the same hence not affecting the cost of computation. In addition The advantage of core memory has made it possible to solve very large problems to be solved on PC's.

The tower has been modeled as a Space Frame, and stiffness method has been used for analysis. The frontal solution method has been used for solution. The wind loads are generated based on the recommendations of IS 875 BDC 37. The members are designed based on IS:800-1984. The designing of towers being non linear problem is solved by iterations. The effect of basewidth, number of panels and bracing type on weight of the tower has been studied for a 50m tower . The effect of height on weight was studied by considering 4 towers of 50m,75m,100m and 125m respectively. The observations are presented in chapter 4.

CHAPTER I

INTRODUCTION

1.1 GENERAL

There has been considerable development in the methods of structural design and erection of large antenna supporting structures consequent to high demand in communication networks . With the stress on the relaying and broadcasting centers to cover larger areas, taller towers are being used. Civil Engineer being entrusted with the job of designing and construction of towers has to choose the right type of tower. The guyed tower though somewhat economical in some situations as far as the amount of steel is concerned,but they require more right of the way, free standing towers are normally chosen for microwave, transmission line and Tv transmission towers.

1.2 General Configuration of The Tower:

Free Standing towers are normally long and slender structures, having narrow tips and wider bases. (Fig 1.1) shows the configuration of a typical free standing tower. The towers are divided into a finite number of panels. In square towers each panel consists of four legs, one at each corner, connected by inclined braces. The joints are sometimes connected by horizontal members in plane of the inclined members, interplanar horizontal braces may also be sometimes used to add to the stability. If the height of the panel is substantial, secondary braces are provided

to decrease the slenderness ratio of the columns and braces. These braces are assumed to carry no load and hence are of nominal size. Communication towers are mounted with antennae dishes for transmitting and receiving signals. At the top of the tower lighting arrangement is generally provided as a warning to the air traffic above. Towers being the tallest structures in the locality are fitted with lightning arresting equipment. Ladders and platforms are provided for maintenance and repairs.

1.3 Design of Towers:

The total cost of a free standing tower depends on [1]

(i) Foundation,
(ii) Tower Members,
(iii) Fabrication and Transportation,
(iv) Erection and
(v) Overheads

The cost of the foundation depends on the geotechnical properties and the loads. The cost of the tower elements depends on the loads and the geometry of the tower. The other costs are roughly proportional to the weight of the tower. Since the loads on the tower are proportional to the sizes of the sections used for the tower members, which themselves depend on the loads, the problem becomes nonlinear and is solved by iterative procedure, which consists of :

(i) Assuming a set of initial sections for the members.

(ii) Calculating the loads based on the assumed member sections.

(iii) Analyzing the tower for the computed loads.

(iv) Designing the members according to the forces acting and updating them and checking for convergence, if convergence is not achieved then repeating the procedure from step(ii).

1.4 Computers in Design

During 1960's[2] electronic computation equipment became readily available. This attracted the attention of the Structural Engineers. Coincidentally technical literature on matrix theory of Structural analysis also began appearing. Since matrix operations are easily adaptable to modern digital computer, the method received wide acceptance as a means of providing fast and accurate solutions to most of Structural Engineering problems.

One of The difficulties which was faced by the designer was preparation of large amount of input data, which created frustration and boredom. This also increased the probability of committing mistakes in the input which could affect the results considerably. This led to the development of the concept of "Computer Aided Design". In this technique a preprocessor specially designed for the particular type of problem is used to generate input data for the main program. This relieves the designer of the botherations of typing large and cumbersome input data. Similarly the results that are obtained from an analysis program are also large, hence postprocessors are developed which can interpret the results of analysis and make

rational decisions, which otherwise the designer would have to make. This technique was developed still further to make the postprocessors powerful enough to design the structures and present the results in such way as may be easily interpreted by the designer as well as the Engineer at the construction site.

1.5 Review of Previous Work:

A limited amount of information can be obtained from the published works on guyed towers and transmission line towers.

The first known paper on analysis and design of transmission line towers is by Bergstorm, Arena and Kramer[3] . This is the state of the art type of paper, describing the salient features of the design of self supporting transmission line towers.

The paper by Anaston[4] describes a computer program written to design optimally a complete transmission line tower of given basic dimensions.

The paper of Robert William[5] describes a very-low frequency antenna system comprising of 13 towers ranging from 996 ft. to 1271 ft. in height, guyed at five levels and connected by a network of conductors, constructed at Northwest Cape in Western Australia. A computer program was developed by considering the towers as continuous beams laterally supported by linear coil springs representing the guys and the tower base.

The paper by Charles Beck et al [6] describes the analysis of 500 Kv single circuit tower. They have modeled the tower as a Space Truss and analysed using STAIR (Structural Analysis Interpretive Routine) Program. The validity of the results was checked by actual full scale model testing satisfactorily.

J.P.Arena [7] has given some useful suggestions regarding the care to be exercised in the design and construction of towers.

In the paper by David Lo et al [8] a program is described which takes the advantage of symmetry and requires only a few nodes and members connectivities the rest being generated by symmetry. The Space Truss approach is used for the analysis, combined by frontal solution technique. They have also described an efficient procedure of renumbering to reduce the frontwidth. They also describe the difficulties faced by the designers when all the members meeting at a joint fall in one plane, making the problem geometrically unstable, resulting in a zero diagonal term in the stiffness matrix with the result the designer has to introduce an extra interplanar fictitious member at all such joints to overcome this difficulty which becomes a cumbersome task. The program developed by them is also capable of generating a graphic output on the screen. The design is carried out by full stress design concept.

Harstchan and Maalek [9] have illustrated the applications of formex algebra in formulating the interconnection pattern of transmission line towers. Their formulation may be used as data in conjunction with a suitable computer software for the purpose of structural analysis or it may be employed in relation to automated graphics. In formulating an interconnection pattern no consideration is given to such aspects as the joining technique, support conditions and loads. This method is very efficient for generation of tower configuration and absolute minimum input is required to generate the full configuration of the tower.

The paper by Daevenport [10] is a classical work on the calculation of Gust Factors which may be applied to the static wind loads to account for the effect of buffeting by gusts and buffeting by vortices and turbulence shed in the structure. The approach is based on certain statistical concepts of Random vibrations. The wind profile has been assumed to obey the power law, the exponent being different for structures in open country and city center. The first mode of vibration has been considered for the derivation of the gust loading factors. But some of the factors used by Davenport are not applicable for structures being designed outside United States.

the review of literature of previous work on CAD at IIT Kanpur has revealed some interesting programs.

The earliest work on CAD can be traced to M. Hariharan [11]. An extensive study of bracing arrangements in the case of transmission line towers has been described. A computer program has also been developed to generate the configuration of transmission line towers. The transmission line tower has been modeled as a Space Truss and solved by stiffness method for different loads. The structure has been designed according to the Indian Standard Specifications for the design of steel structures.

I.S. Sharma [12]in his thesis "Automated Optimum Design Of Tall Multilevel Guyed Towers" , has modeled the tower as a beam column hinged or fixed at the base, the guys have been modeled as nonlinear springs, the analysis is initiated by allowing the tower to undergo some initial fictitious displacement at the guy levels. Equilibrium equations are then derived for wind loads and refined displacements are arrived at this process is repeated till the problem converges. The cost of the tower is minimised by using Powell's algorithm.

A program HIRISE developed by Dr. P. Dayaratnam is an efficient and compact package for the design of multistorey buildings, roof trusses, and towers. This program consists of a preprocessor that is capable of

generating configuration of multistorey building frames and plotting them on the line printer. The second part is the analysis and design program, this accepts the data from the preprocessor and generates the loads and analyses and designs the structure. This program has an excellent network of control switches and error detection devices so that a quick and efficient design can be obtained. The author was associated with the program for some time which has given light to many useful programming aspects.

M.Tech thesis "Computer Aided Design of Industrial Buildings" by A.K.Sharma [13] is a package which analyses and designs the various components of an Industrial Building. It has an excellent preprocessor which generates the geometry and loads, it is interactive and has graphic support.

V.V.Sitaraman [14] have developed an excellent package on CAD of small industrial buildings. This program is capable of generating various types of industrial trusses, it is very versatile and members and joints can be generated as required, the program optimises the joint numbering for optimum bandwidth, this program is capable to generate the loads and design the complete structure upto the foundations.

M.Tech thesis "Computer Aided Design and Reliability Analysis of Transmission Line Towers" by A.S.Madhava Rao [15] is a package for the Analysis and design of

transmission line towers. This includes a preprocessor for the generation of the geometry of the tower. This loads are also computed by the program, this includes the effect of dead, wind, and conductor loads, broken wire loads are also computed by the program to design the tower, a Space Truss approach has been used for the analysis. The probability of failure of each member is also computed thereby, determining the probability of failure of the whole system.

1.6 Scope Of The Work:

A Computer program for the analysis and design of towers has been developed confirming to the recommendations of IS:875 BDC 37 ,and IS:800 1984. The main emphasis has been on the development of a preprocessor for the automated generation of the geometry of the tower with only little more than a conceptual information being desired from the designer. An attempt has been made to reduce the number of control switches required to control the flow of the program without affecting its flexibility. The designer has been relieved of the responsibility of numbering the joints and members carefully. The secondary bracing has also been generated requiring the most basic decision making variables. An Initial guess is required from the designer, this guess may reduce the number of iterations if provided properly based on the designers experience and save a large amount of computation time. The program is still useful for an

inexperienced designer, the only difference being the computation time increases.

A data manipulation program has also been developed with a database from which the designer may choose the sections available to him,this is a complete interactive program and menu driven, this helps the designer to select or drop any particular section from the database to be used by the program. This relieves the designer from typing the sectional properties available every time he designs a tower, hence saving time.

The analysis and design program utilises the data generated by the preprocessor some of the basic information is required for the analysis and design of the tower the number of loading combinations is unlimited without increasing any core memory requirement, enhancing the utilization of the package. The wind load calculation are made as per the recommendations of IS:875 BDC 37. The design is based on the assumption that the members carry only axial loads, and confirms the requirement of IS 800. The problem being nonlinear is solved by iterations and the program is capable of iterating to the desired number of iterations until convergence is achieved.

A parametric study considering the effect of bracing arrangement, the effect of change of base width of the tower, and the effect of number of panels in a tower has been carried out for a 50m tower. The effect of height on

the weight of the tower has also been studied for a particular wind zone such as that of Kanpur. The results and discussions are given in chapter IV.

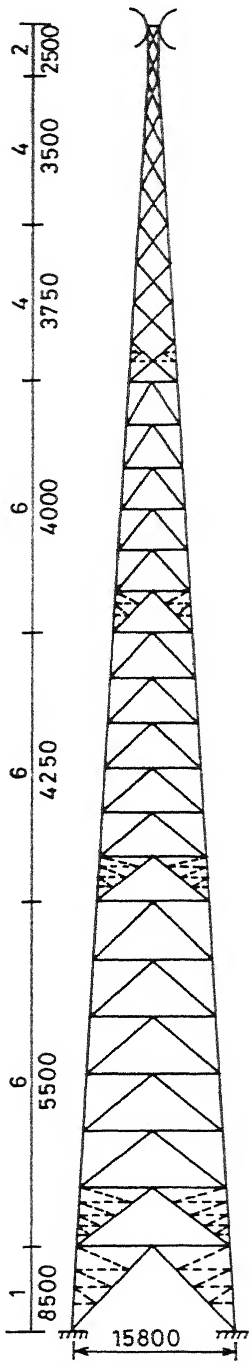


Fig. 1.1 Configuration of a typical tower.

CHAPTER II

STRUCTURAL ANALYSIS AND DESIGN FORMULATION

2.1 GENERAL:

The stiffness method is the most common method used in matrix analysis of structures. One of the advantages of the stiffness method over the flexibility method is the ease of programming, it does not need complicated decision making modules once the structure has been defined completely. Further the stiffness matrix is known to be sparsely filled and a symmetric matrix, hence modern solution techniques like skyline, banded skyline, and frontal solution techniques may be employed to solve large problems occupying relatively smaller dimensioned space. Considering these advantages the stiffness method of analysis has been chosen. This method being described extensively in many books [16] is only described briefly here.

2.2 STIFFNESS METHOD

The stiffness method basically consists of developing the joint equilibrium equations in terms of stiffness coefficients and unknown joint displacements.

$$[K_s]\{D_s\}=\{F_s\} \qquad \text{. . . . .(2.1)}$$

Where

$[K_s]$ is the global stiffness matrix

$\{D_s\}$ is the unknown displacement vector

$\{F_s\}$ is the global load vector.

In the above equation each of the in d.o.f the global stiffness is derived considering the effect of all the elements meeting at a joint and contributing to that particular d.o.f.

The element stiffness matrix coefficients may be derived by considering the element and restraining it at the ends, the j^{th} stiffness coefficient for the i^{th} degree of freedom is equal to end action required to be applied to at the j^{th} degree of freedom, to produce a deformation of unity at the i^{th} degree of freedom. Generally it is convenient to first derive the stiffness coefficient matrix considering the member axes (Fig. 2.1a) as reference. Hence the equation of equilibrium may be written as .

$$\begin{bmatrix} K_{mii} & K_{mij} \\ K_{mji} & K_{mjj} \end{bmatrix} \begin{bmatrix} D_{mi} \\ D_{mj} \end{bmatrix} = \begin{bmatrix} F_{mi} \\ F_{mj} \end{bmatrix} \qquad \ldots\ldots.(2.2)$$

But for the sake of compatibility with other elements it becomes necessary to transform the member axes into a global system (Fig. 2.1b). Hence a transformation matrix [R] is used. This matrix transforms the global axes to the member axes. Hence

$$A_m = R\ A_s$$

using this in equation 2.2

$$\begin{bmatrix} K_{mii} & K_{mij} \\ K_{mji} & K_{mjj} \end{bmatrix} \begin{bmatrix} R\ D_{si} \\ R\ D_{sj} \end{bmatrix} = \begin{bmatrix} R\ F_{si} \\ R\ F_{sj} \end{bmatrix} \quad \ldots\ldots\ldots(2.3)$$

This equation may be written as:

$$\begin{bmatrix} K_{mii} & K_{mij} \\ K_{mji} & K_{mjj} \end{bmatrix} \begin{bmatrix} R & O \\ O & R \end{bmatrix} \begin{bmatrix} D_{si} \\ D_{sj} \end{bmatrix} = \begin{bmatrix} R & O \\ O & R \end{bmatrix} \begin{bmatrix} F_{si} \\ F_{sj} \end{bmatrix} \quad ..(2.4)$$

This equation may be written as

$[K_m]\ [R_T]\ \{D_s\} = [R_T]\ \{F_s\}$

Pre multiplying both equations by $[R_T]^{-1}$

$[R_T]^{-1}\ [K_m]\ [R_T]\ \{D_s\} = [R_T]^{-1}\ [R_T]\ \{F_s\}$

It has been found that the inverse of the transformation matrix is equal to the transpose of the matrix for an orthogonal set of axes.

therefore $[R_T]^T\ [K_m]\ [R_T]\ \{D_s\} = [I]\ \{F_s\}$

denoting $[R_T]^T\ [K_m]\ [R_T]$ by $[K_s]$

The equation leads to equation 2.1

$$[K_s]\ \{D_s\} = \{F_s\}$$

The unknown displacements can be computed by solving the equations.

After the displacements at each degree of freedom have been computed the forces in each of the members may be computed by using the same equation at the member level.

$$[K_s]^e\ \{D_s\} = \{F_s\}^e$$

The forces thus obtained are then required to be

transformed in the member directions to give the member forces. The equilibrium condition is satisfied at the member level by adding the element forces due to the element loads in the restrained condition.

$$\{F_m\}^e = \{F_{Am}\}^e + [R_T]\{F_s\}^e$$

$$\{F_m\}^e = -\{F_{Am}\}^e + [R_T][K_s]^e \{D_s\}$$

2.2.1 Analysis by Space Truss:

When considering the structure as a space truss, as the joints are considered to be pin connected therefore there is no moment possible, and there are only three degrees of freedoms at each of the nodes i.e. the axial force and two shears in the two directions perpendicular to the axes of the member (Fig. 2.1a). The stiffness in the member direction and the rotation transformation matrices are given in (Fig.2.2).

2.2.2 Analysis by Space Frame:

When considering the structure as a space frame, there are six degrees of freedoms at each joints, axial force, two shears, torsion and two bending moments along the two perpendicular axes (Fig. 2.3). A space frame member may have its principal axes Y_m and Z_m oriented in general direction, the orientation can be defined by defining the angle alpha (Fig. 2.5). This can also be defined by defining a K-node through which the principal plane of the member passes, from which the angle alpha may be derived.

Hence defining the member completely. The space frame member matrix is given in (Fig. 2.4) and the transformation matrices in (Fig.2.6).

2.3 Solution Technique:

There are many standard techniques available for the solution of the simultaneous equations like Gauss Jordan, Gauss Elimination etc. Recognizing that the global stiffness matrix formed is symmetric and banded sparse some special purpose techniques like Banded solution and Skyline solution techniques are available. These techniques although better than the previously mentioned are still insufficient in solving problems of higher number of degree of freedoms as the size of the stiffness matrix becomes very large. Hence a new technique was evolved by Irons [17], this utilizes the fact that after a node has been completely assembled it does not undergo any further operations and the variables may be eliminated and written on the disk in the form of an equation, thereby vacating the core memory space occupied by the equation of that particular degree of freedom. Hence saving considerably the core memory of the computer, so that larger and more complicated problems can be solved by this technique. The present problem being reasonably large this technique has been used.

The main [18] idea of the frontal solution is to assemble the equations and eliminate the variables at the

same time. As soon as the coefficient of an equation are completely assembled from the contribution of all relevant elements, the corresponding variable can be eliminated. Therefore the complete structural stiffness matrix is never formed as such, since after elimination the reduced equation is immediately transferred to the disk storage. The core contains at any given instant, the upper triangular part of a square matrix containing the equations which are being formed at that particular time. These equations, Their corresponding nodes and degree of freedom are termed the front. The number of unknowns in the front is the front width. The equations, node and degree of freedom belonging to the front are termed active, those which are yet to be considered are termed inactive, those which have passed through the front and have been eliminated are said to be deactivated.

During the assembly and elimination process the elements are considered each in turn according to their order. This differentiates it form the banded matrix solution. Here the ordering of the element is crucial and the ordering of the node numbers is irrelevant. The process consists of reading the stiffness matrix of each element in order repetitively and then the stiffness matrix is summed into the equation if the nodes are already active,or new equations are formed and included in the front if the nodes are being activated for the first

time. If some nodes are appearing for the last time, the corresponding equations are eliminated and stored on the disk file and are then deactivated. The free space is utilized in the assembly of the next element. A brief flow chart of the procedure is given in (Fig.2.7).

2.4 Loads on Towers:

The loads on the tower consist of
(1) Member weights
(2) Platform and Railing weights
(3) Antenna weights
(4) Ladder and Lift loads
(5) Gussets and Secondary bracing loads
(6) Wind loads
(7) Seismic loads
(8) Erection Loads
(9) Live Loads

The first five sets of loads are fixed type of which member weights depends on the sizes of the sections used the others being governed by the functional aspect of the structure. The wind loads are the most important of all the loads and generally govern the design of towers. Towers being very light structures the seismic load is normally very small as compared with the wind loads and does not govern the design, hence is not considered in the present work. Erection loads are also considered to be negligible and not considered in the design the live loads on the towers are negligible when compared with the other and hence are also eluded.

The loads due to the member weights is determined by calculating the loads of each of the members and distributing it between the two joints connecting it. The

platform and railing weights, antenna weights and ladder weights may be applied as extra loads on the structure at the particular joint where they contribute. The loads due to secondary bracings is calculated by computing the total weights of secondary bracing on each panel and distributing it between the corner joints of the panel.

2.4.1 Wind Loads:

Wind is air in motion relative to the surface of the earth. The primary cause of wind is traced to earth's rotation and differences in terrestrial radiation. The wind generally blows horizontally to the ground, at high wind speeds. Since vertical component of atmospheric motion is relatively small, the term wind denotes almost exclusively the horizontal wind, vertical wind being always identified as such. The wind speeds are measured with the aid of anemometers which are generally installed at the heights varying from 10m to 30m above the ground.

The calculation procedure of wind loads for tower based on the recommendation of IS 875: BDC 37 is briefly described below.

The design wind speed at a particular height is the basic wind speed in that area modified by the following factors

(a) Risk Coefficient (K_1) (Fig. 2.8) gives the basic wind speed as are used for the calculation of wind loads in India, these wind speeds are based on a mean return period

of 50 years, as communication towers are important structures, therefore they are designed for a return wind period of 100 years, hence a factor of 1.05 is used for the computation of design wind velocity.

(b) Terrain, Height and Structure size factor (K_2): The Indian Standards has divided the terrains into four categories based on the obstruction which contributes to the ground surface roughness.

(1) Category 1: Exposed open terrain with few of no obstruction in which the average height of any object in the vicinity of the structure is less than 1.5m.

(2) Category 2: Open terrain with well scattered obstructions having heights generally 1.5m to 10m.

(3) Category 3: A terrain with numerous closely spaced obstruction having the size of buildings scattered upto 10m height with or without a few isolated tall structures.

(4) Category 4: Terrain with numerous large highly closely spaced obstructions.

Depending on the largest dimension of the structure the structures are divided into three classes

(1) Class A: This class consists of structures having their maximum dimension less than 20m. This includes very small towers like some of transmission line towers.

(2) Class B: This consists of structures having their maximum dimensions between 20m and 50m. Small towers may be included in this class.

(3) Class C: This consists of structures having their

maximum dimension greater than 50m.

Depending on the height of the structure, the class of the structure and the terrain category of the structure the factor K_2 is interpolated from the Table 2.1.

(c) Topography factor K_3 : The wind speed at any given site is influenced by local topography . The effect of topography is to accelerate wind near the summits or crests of hills , and decelerate the wind in valleys or near the foot of steep ridges. This effect is significant at a site where the upward slope greater than 3^o, but for normal ground conditions the topography factors may be assumed to be 1.0.

The design wind pressure is calculated based on the design wind speed by the relation given below

$$P_z = 0.6 \ V_z^2$$

where P_z is the design wind pressure in N/m2 at the height of Z m.

and V_z is the design wind velocity in m/s at height Z m.

The coefficient 0.6 has been derived form a number of factors like the atmospheric pressure, density of the air,temperature etc.

The forces on the towers are calculated form the relation $F=C_f A_c \ P_z$

where A_e is the effective frontal area of the tower, this is calculated by projecting the first face of the tower on the Y-Z plane . Hence while computing the effective frontal area of the tower, each member on the face 1 of the tower is projected on the Y-Z plane and the area

obstructed is calculated.

The force coefficient C_f depends on

(a) The shape of the tower :C_f depends on whether the tower is square in plan or triangular in plan. For triangular base towers the force coefficients are notably less as can be seen from Table 2.2.

(b) The solidity ratio: This is a ratio of the effective frontal area and the total area, it gives an idea of the sizes of the members and normally varies between 0.1 and 0.5 for towers. It can be observed that as the solidity ratio increases the force coefficient decreases, this can be attributed to the effect of vortex formation at the edges of the members, which creates a suction force due to the turbulence at the Lee-ward side.

(c) The shape of the individual member: It can be seen from the comparison of Table 2.2 and Table 2.3 that circular members being smooth have less force acting on them as there is less separation of the boundary layer and the vortices are not formed. Further observing the Table 2.3 more carefully it can be noted that when DV_d i.e. the obstructed area per unit length increases the coefficient C_f also decreases.

(d) The direction of wind:For towers with flat sided members the coefficient C_f is equal to 1.2 when the wind is considered to be blowing from the corner, this considers the effect of the increase in frontal area in comparison to the effective frontal area when the wind is blowing perpendicular to one face,hence A_e is taken as

same when calculating the load for the case when the wind is blowing perpendicular to the face. The coefficients for the tower composed of flat sided is also changed when the wind is blowing from a corner Table 2.3, to take into account the increase in frontal area.

The forces as calculated from the above relations for each panel is distributed amongst the corner nodes of the panel ,thus leading to two cases of wind loads on the tower i.e. (i) Wind blowing perpendicular to a face and (ii) Wind blowing from corner.

The wind loads on the antenna can also be calculated similarly, the only difference being that antenna structures are curved in shape, hence the wind reflects and turbulence is caused in the immediate vicinity of the antenna. The wind forces acting on the antenna depend on type of curvature of the antenna with respect to the direction of the wind ,this can be calculated based on the recommendations of IS:875 BDC 37. (Fig. 2.9).

2.5 DESIGN OF TOWERS:

In the present study primary analysis of towers has been considered, local bending of the members has been neglected, hence the shear and moments are not very significant in the design. The members are designed as axial load carrying units and are identified as compression and tension members,these are designed based on the recommendations of IS:800-1984.

2.5.1 Design of Compression Members:

The allowable stress in a compression member is calculated by the equation [IS:800-1984]

$$\sigma_{ac} = 0.6\ f_{cc}\ f_y / \left[(f_{cc})^{1.4} + (f_y)^{1.4}\right]^{1/1.4}$$

where σ_{ac} =Permissible stress in axial compression

f_y = yield stress in steel

f_{cc} =elastic critical stress in compression

E =modulus of elasticity

The effective length is calculated as 0.85 times the unsupported length. If the columns are very long, secondary braces can be provided to reduce the effective length. The stress ratio is calculated as a ratio of actual stress and allowable stress. The member is designed for a stress ratio between 0.85 and 0.95,if the stress ratio is more or less than these limits the members are revised.

2.5.2 Design of Tension Members:

The allowable stress σ_{at} for tension members is calculated as $0.6f_y$. The net effective area of the members are calculated according to the codal provisions, and the stress ratio is calculated,the members are designed as per the allowable stress ratio limits of 0.85 and 0.95.

An optimum design can thus be obtained theoretically, but sometimes it is practically advisable to choose the sections rationally. If the column members are changed in each panel then the cost of lapping, cutting may become very high. Hence as far as possible efforts are made to

use the members in the tower without cutting them, so that the cost of lapping is least,this also reduces the weight of the tower as some length of the member is wasted in lapping which increases the weight of the tower.

TABLE- 2.1

FACTORS TO OBTAIN DESIGN WIND SPEED VARIATION WITH HEIGHT IN DIFFERENT TERRAINS FOR DIFFERENT CLASSES OF BUILDING STRUCTRES

Ht. m	CATEGORY 1			CATEGORY 2			CATEGORY 3			CATEGORY 4		
	A	B	C	A	B	C	A	B	C	A	B	C
5	0.99	0.97	0.93	0.92	0.90	0.85	0.80	0.78	0.71	0.80	0.76	0.67
10	1.05	1.03	0.99	1.00	0.98	0.93	0.91	0.86	0.82	0.80	0.76	0.67
15	1.09	1.07	1.03	1.05	1.02	0.97	0.97	0.94	0.87	0.80	0.76	0.67
20	1.12	1.10	1.06	1.07	1.05	1.00	1.01	0.98	0.91	0.80	0.76	0.67
30	1.15	1.13	1.09	1.12	1.10	1.04	1.06	1.03	0.96	0.97	0.93	0.83
50	1.20	1.18	1.14	1.17	1.15	1.10	1.12	1.09	1.02	1.10	1.05	0.95
100	1.26	1.24	1.20	1.24	1.22	1.17	1.20	1.17	1.00	1.20	1.15	1.05
150	1.30	1.28	1.24	1.28	1.25	1.21	1.24	1.21	1.15	1.24	1.20	1.10
200	1.32	1.30	1.26	1.30	1.28	1.24	1.27	1.24	1.18	1.27	1.22	1.13
250	1.34	1.32	1.28	1.32	1.31	1.26	1.29	1.26	1.20	1.28	1.24	1.16
300	1.35	1.34	1.30	1.34	1.32	1.28	1.31	1.26	1.22	1.30	1.26	1.17
350	1.37	1.35	1.31	1.36	1.34	1.29	1.32	1.30	1.24	1.31	1.27	1.19
400	1.38	1.36	1.32	1.37	1.35	1.30	1.34	1.31	1.25	1.32	1.28	1.20
450	1.39	1.37	1.33	1.38	1.36	1.31	1.35	1.32	1.26	1.33	1.29	1.21
500	1.40	1.38	1.34	1.39	1.37	1.32	1.36	1.33	1.28	1.34	1.30	1.22

TABLE- 2.2

OVERALL FORCE COEFFICIENT FOR TOWERS

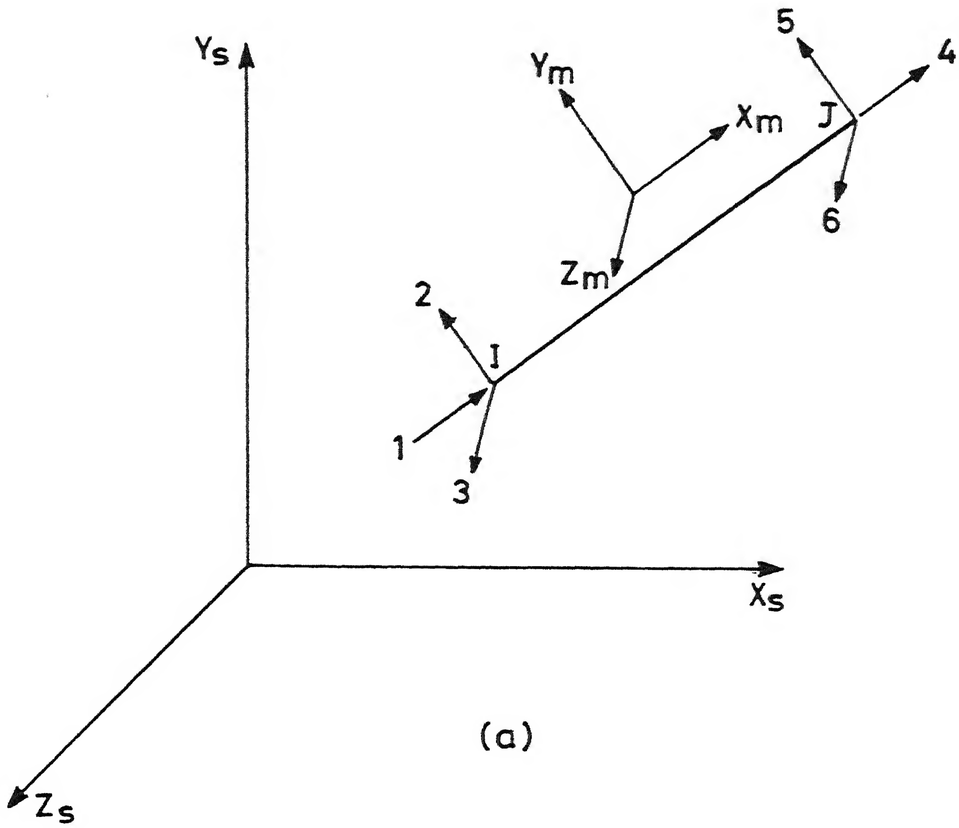
COMPOSED OF FLAT SIDED MEMBERS

Solidity Ratio	Force coefficient for	
	Square Tower	Equilateral Triangular Tower
0.1	3.8	3.1
0.2	3.3	2.7
0.3	2.8	2.3
0.4	2.3	1.9
0.5	2.1	1.5

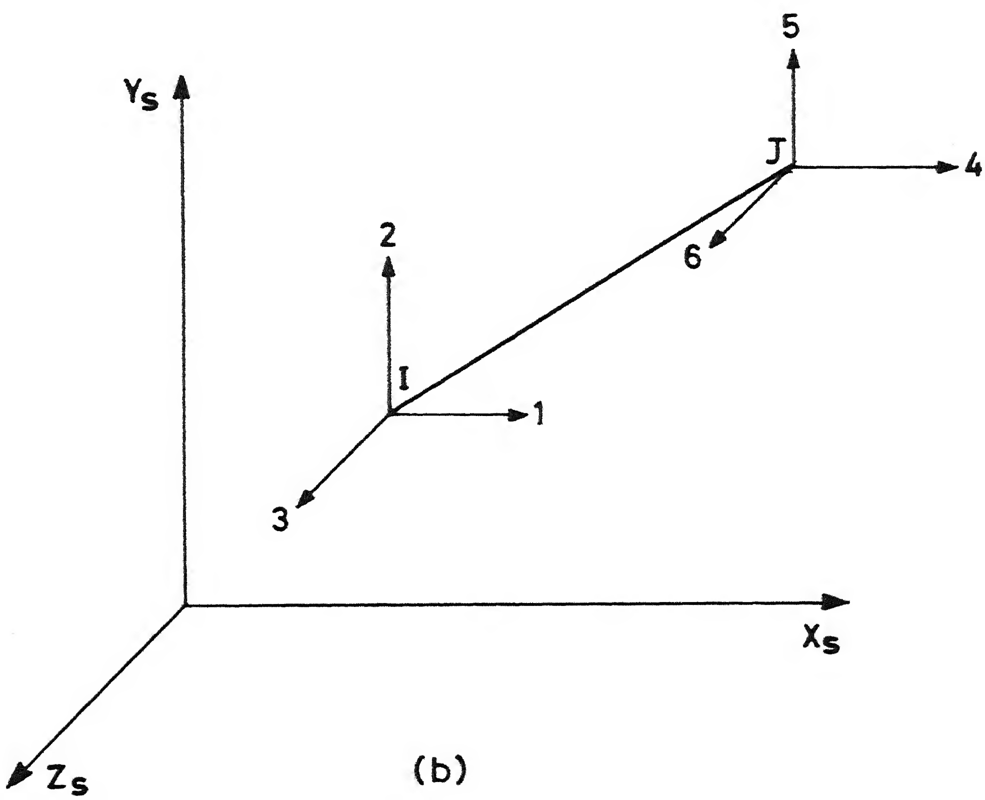
TABLE -2.3

OVERALL FORCE COEFFICIENT FOR SQUARE TOWERS
COMPOSED OF ROUNDED MEMBERS

Solidity Ratio of Frontal Face	Force Coefficient for			
	Subcritical Flow ($DV_d < 6\ m^2/s$)		Supercritical Flow ($DV_d \geq 6\ m^2/s$)	
	onto face	onto corner	onto face	onto corner
0.05	2.4	2.5	1.1	1.2
0.10	2.2	2.3	1.2	1.3
0.20	1.9	2.1	1.3	1.6
0.30	1.7	1.9	1.4	1.6
0.40	1.6	1.9	1.4	1.6
0.50	1.4	1.9	1.4	1.6



(a)



(b)

Fig. 2.1 Member and global axes orientation of space truss member.

$$[K_m]^e = \begin{bmatrix} \frac{EA_x}{L} & 0 & 0 & -\frac{EA_x}{L} & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 \\ -\frac{EA_x}{L} & 0 & 0 & \frac{EA_x}{L} & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 \end{bmatrix}$$

MEMBER STIFFNESS MATRIX OF A SPACE TRUSS MEMBER

$$[R] = \begin{bmatrix} C_x & C_y & C_z \\ -\frac{C_x C_y}{C_{xz}} & C_{xz} & -\frac{C_y C_z}{C_{xz}} \\ -\frac{C_z}{C_{xz}} & 0 & \frac{C_x}{C_{xz}} \end{bmatrix}$$

TRANSFOMATION MATRIX FOR INCLINED MEMBER

$$[R_{ver}] = \begin{bmatrix} 0 & C_y & 0 \\ -C_y & 0 & 0 \\ 0 & 0 & 1 \end{bmatrix}$$

TRANSFORMATION MATRIX FOR VERTICAL MEMBER

$$C_x = \cos(x)$$
$$C_y = \cos(y)$$
$$C_{xz} = \sqrt{\cos(x)^2 + \cos(z)^2}$$

FIG. 2.2 STIFFNESS AND ROTATION MATRICES OF A SPACE TRUSS MEMBER

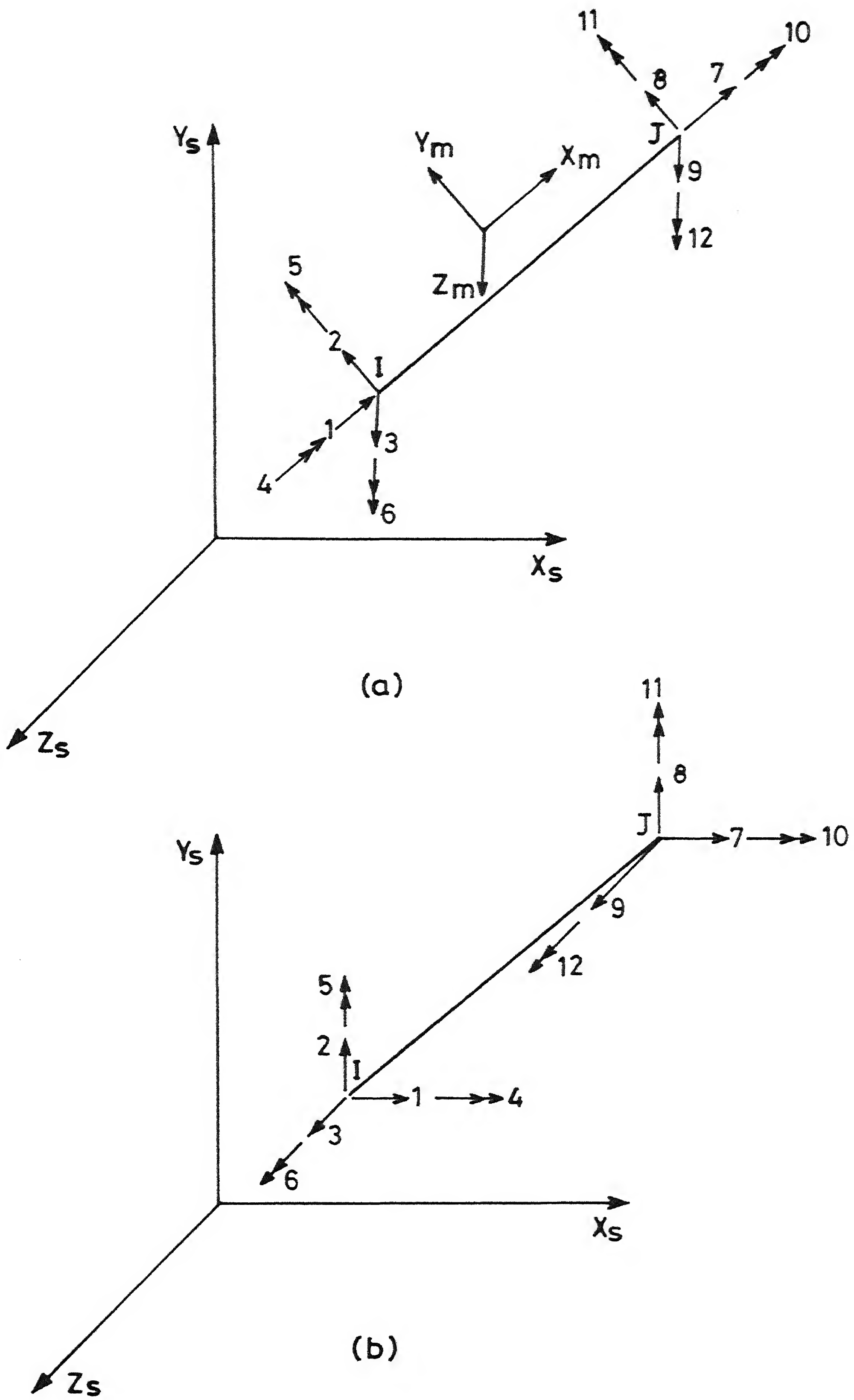


Fig. 2.3 Member and global axes orientation of a space frame member.

$$
\begin{bmatrix}
\frac{EA_x}{L} & 0 & 0 & 0 & 0 & 0 & -\frac{EA_x}{L} & 0 & 0 & 0 & 0 & 0 \\
0 & \frac{12EI_z}{L^3} & 0 & 0 & 0 & \frac{6EI_z}{L^2} & 0 & -\frac{12EI_z}{L^3} & 0 & 0 & 0 & \frac{6EI_z}{L^2} \\
0 & 0 & \frac{12EI_y}{L^3} & 0 & -\frac{6EI_y}{L^2} & 0 & 0 & 0 & -\frac{12EI_y}{L^3} & 0 & -\frac{6EI_y}{L^2} & 0 \\
0 & 0 & 0 & \frac{GI_x}{L} & 0 & 0 & 0 & 0 & 0 & -\frac{GI_x}{L} & 0 & 0 \\
0 & 0 & -\frac{6EI_y}{L^2} & 0 & \frac{4EI_y}{L} & 0 & 0 & 0 & \frac{6EI_y}{L^2} & 0 & \frac{2EI_y}{L} & 0 \\
0 & \frac{6EI_z}{L^2} & 0 & 0 & 0 & \frac{4EI_z}{L} & 0 & -\frac{6EI_z}{L} & 0 & 0 & 0 & \frac{2EI_z}{L} \\
-\frac{EA_x}{L} & 0 & 0 & 0 & 0 & 0 & \frac{EA_x}{L} & 0 & 0 & 0 & 0 & 0 \\
0 & -\frac{12EI_z}{L^3} & 0 & 0 & 0 & -\frac{6EI_z}{L^2} & 0 & \frac{12EI_z}{L^3} & 0 & 0 & 0 & -\frac{6EI_z}{L^2} \\
0 & 0 & -\frac{12EI_y}{L^3} & 0 & \frac{6EI_y}{L^2} & 0 & 0 & 0 & \frac{12EI_y}{L^3} & 0 & \frac{6EI_y}{L^2} & 0 \\
0 & 0 & 0 & -\frac{GI_x}{L} & 0 & 0 & 0 & 0 & 0 & \frac{GI_x}{L} & 0 & 0 \\
0 & 0 & -\frac{6EI_y}{L^2} & 0 & \frac{2EI_y}{L} & 0 & 0 & 0 & \frac{6EI_y}{L^2} & 0 & \frac{4EI_y}{L} & 0 \\
0 & \frac{6EI_z}{L^2} & 0 & 0 & 0 & \frac{2EI_z}{L} & 0 & -\frac{6EI_z}{L} & 0 & 0 & 0 & \frac{4EI_z}{L}
\end{bmatrix}
$$

FIG. 2.4 MEMBER STIFFNESS FOR A SPACE FRAME MEMBER

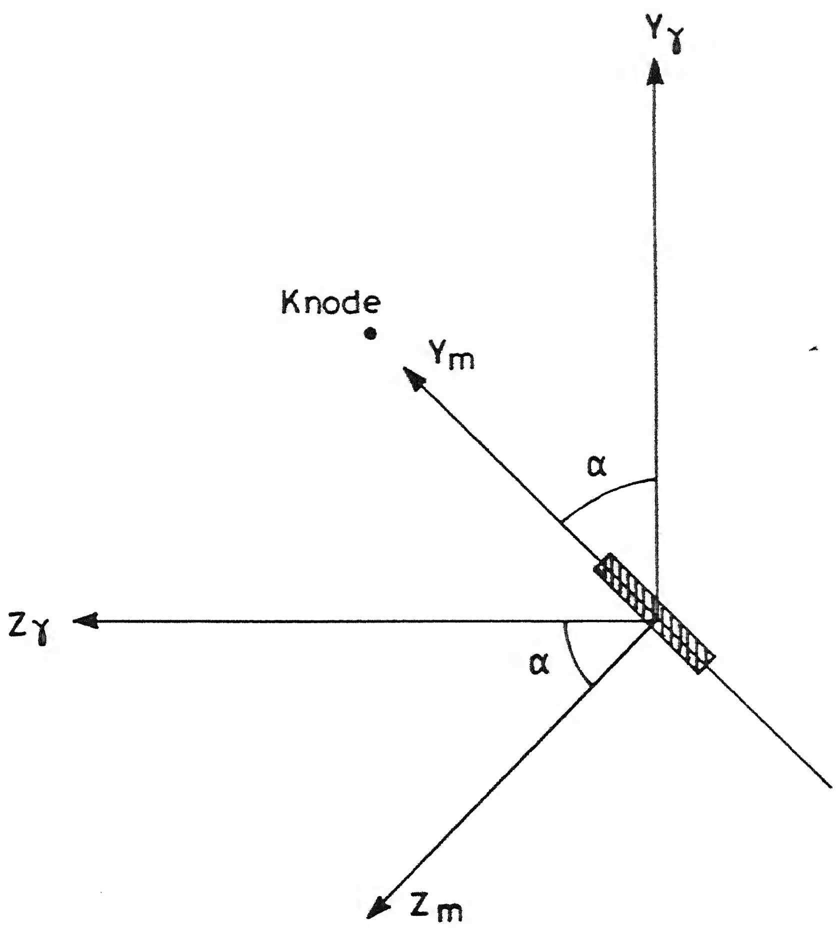


Fig. 2.5 Orientation of member about X_m.

$$R_T = \begin{bmatrix} [R] & 0 & 0 & 0 \\ 0 & [R] & 0 & 0 \\ 0 & 0 & [R] & 0 \\ 0 & 0 & 0 & [R] \end{bmatrix}$$

ASSEMBLY OF R_T FOR A SPACE FRAME MEMBER

$$[R] = \begin{bmatrix} C_x & C_y & C_z \\ \dfrac{C_xC_y \cos\alpha - C_z \sin\alpha}{C_{xz}} & C_{xz} \cos\alpha & \dfrac{-C_yC_z \cos\alpha + C_x \sin\alpha}{C_{xz}} \\ \dfrac{C_xC_y \sin\alpha - C_z \cos\alpha}{C_{xz}} & C_{xz} \sin\alpha & \dfrac{C_yC_z \sin\alpha + C_x \cos\alpha}{C_{xz}} \end{bmatrix}$$

ROTATION TRANSFORMATION MATRIX FOR AN INCLINED MEMBER

$$[R_{ver}] = \begin{bmatrix} 0 & C_y & 0 \\ -C_y \cos\alpha & 0 & \sin\alpha \\ C_y \cos\alpha & 0 & \cos\alpha \end{bmatrix}$$

ROTATION TRANSFORMATION MATRIX FOR A VERTICAL MEMBER

FIG 2.6 ROTATION MATRICES OF A SPACE FRAME MEMBER

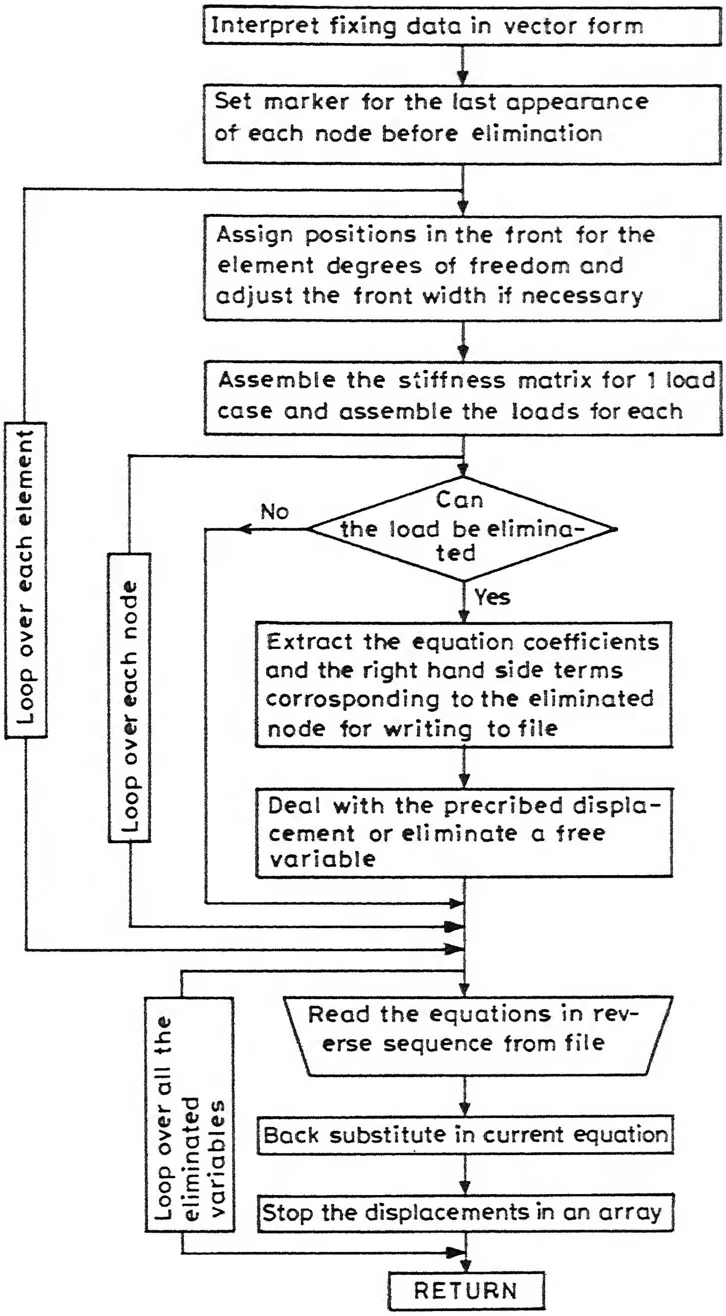


Fig. 2.7 Frontal solution subroutine.

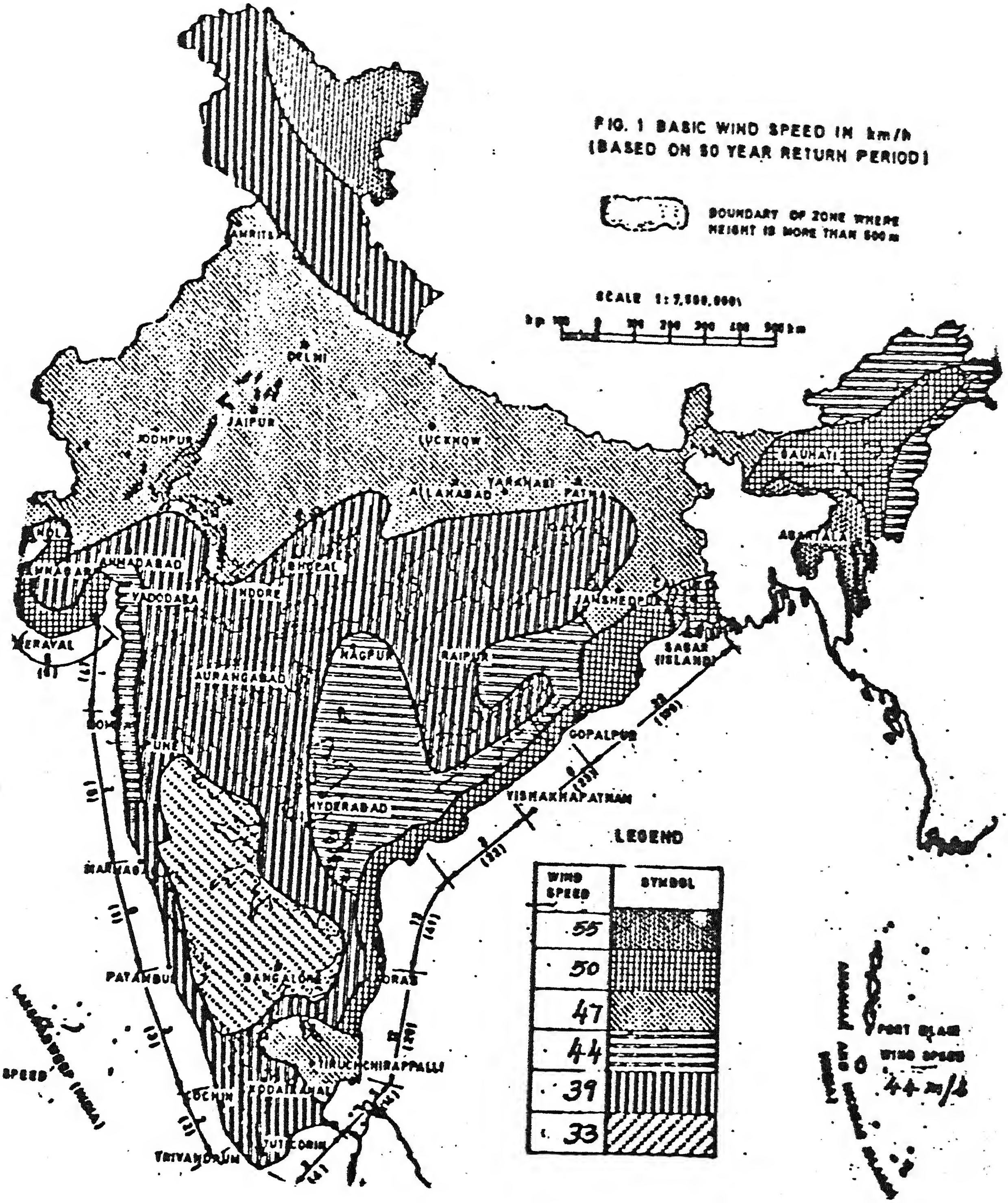


Fig. 2.8 Basic wind speed in m/s (based on 50 year return period)

37

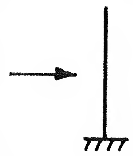
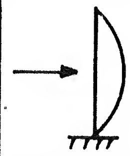
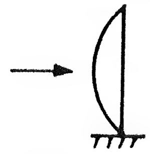
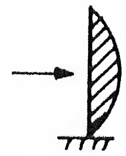
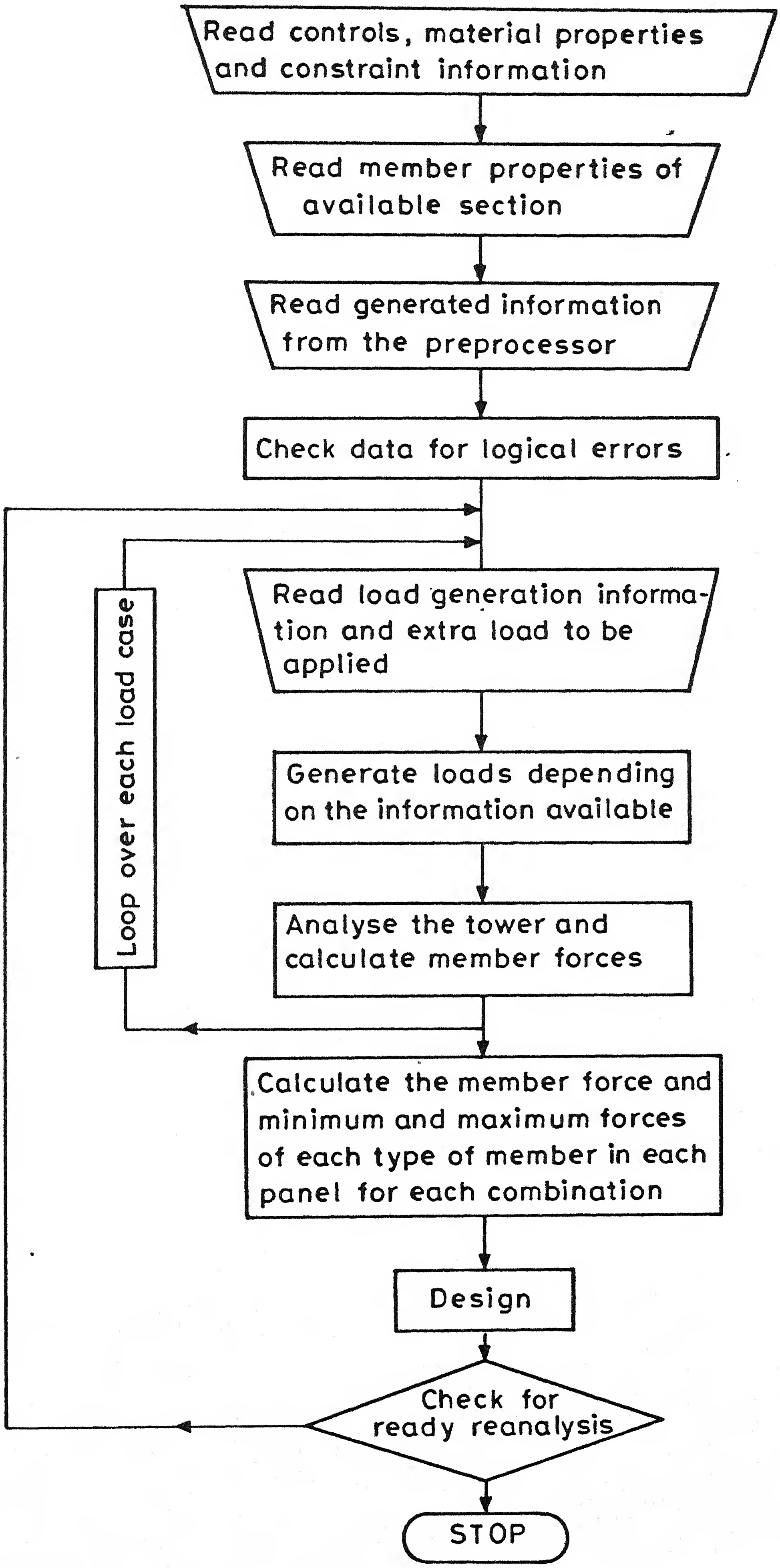
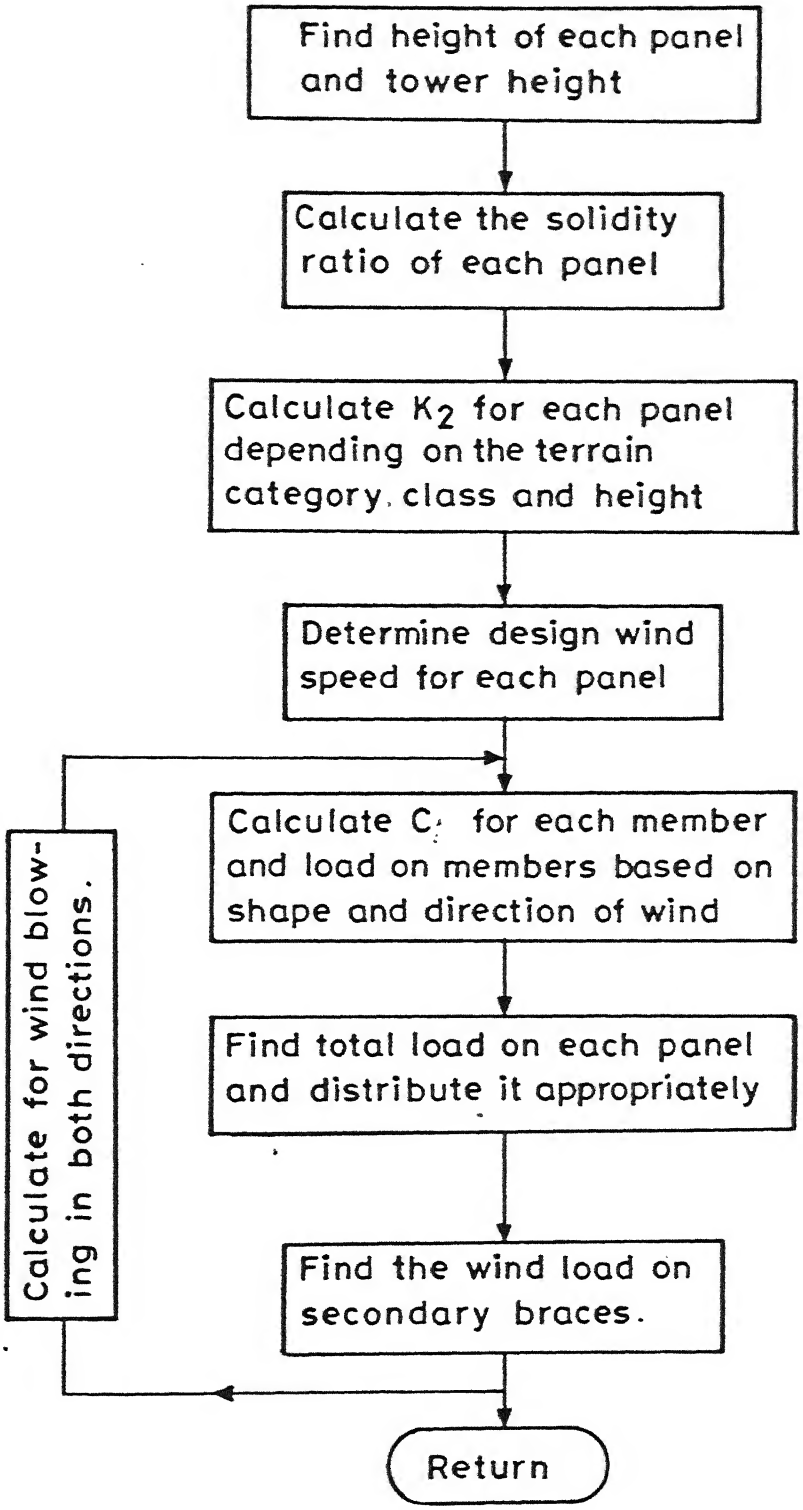
Shape				
C_f	1.2	1.4	0.4	1.2

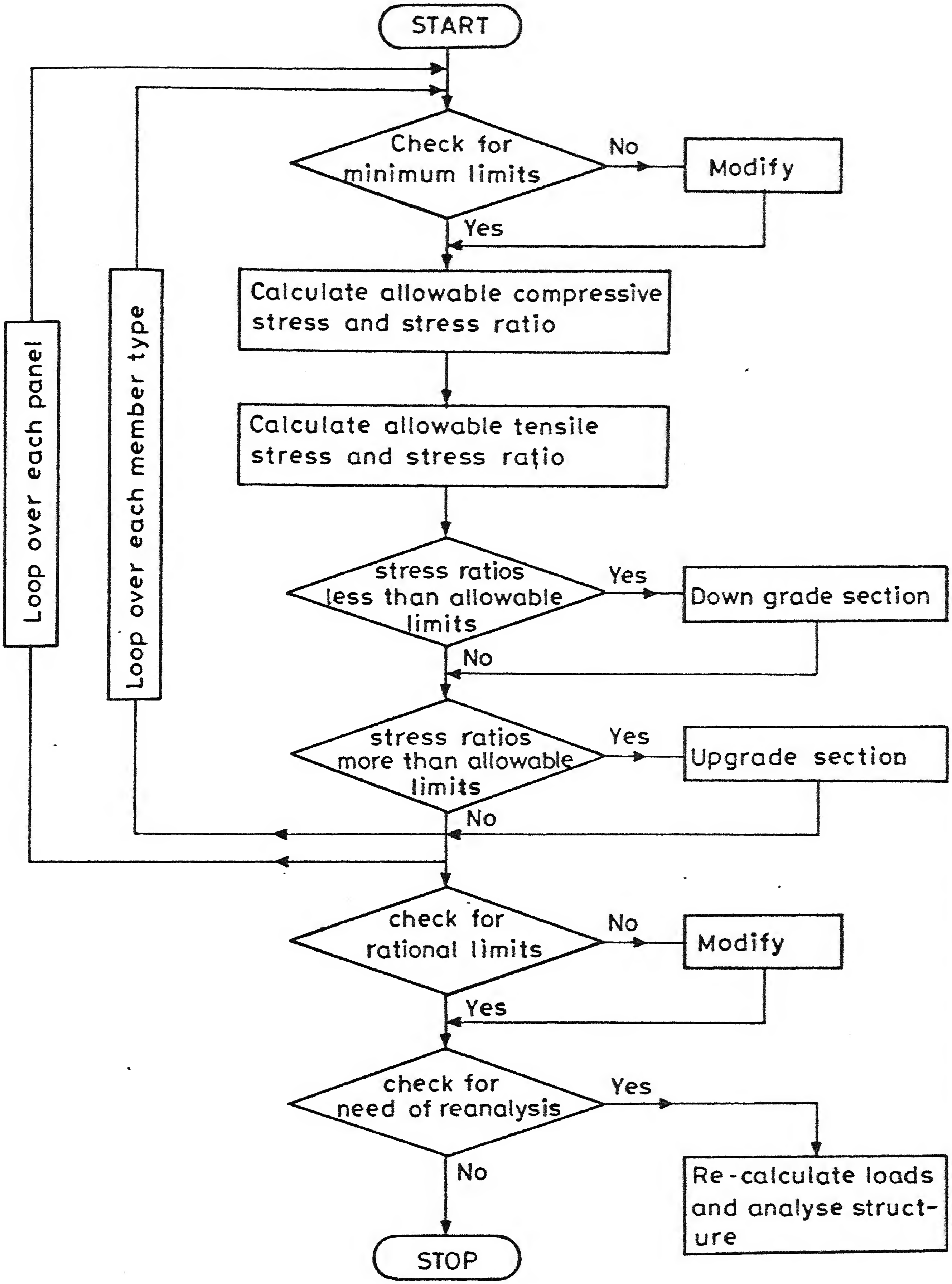
Fig. 2.9 Force coefficients for solid shapes mounted on a surface.



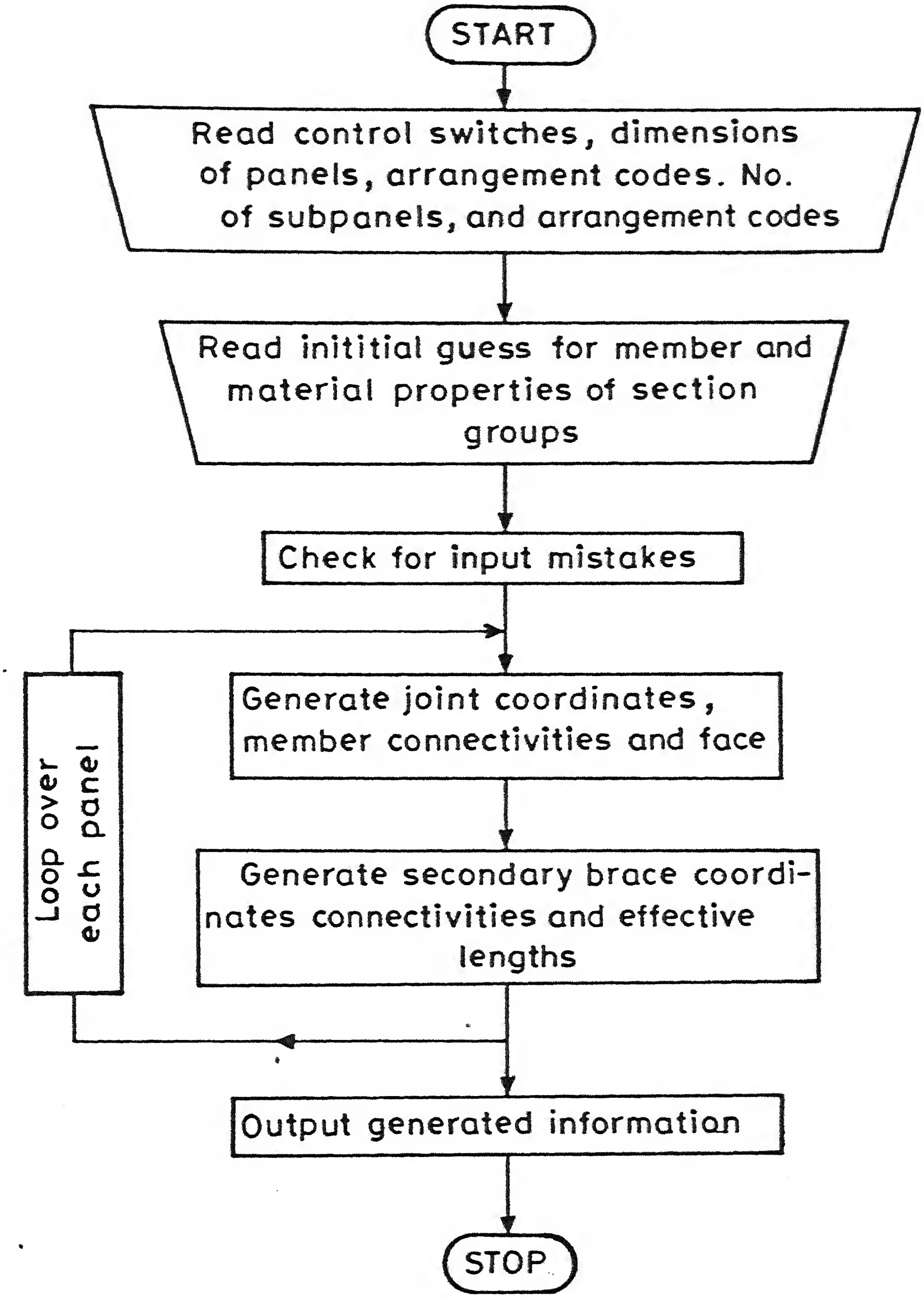
General flow chart



Flow chart for calculation of wind load.



Flow chart for design.



Flow chart for preprocessor.

CHAPTER III

COMPUTER AIDED DESIGN OF TOWERS

3.1 GENERAL:

As the name CAD suggests, it is the use of computers as an aid by the designer to design the structure efficiently with minimum effort and time. This calls for the development of special purpose programs which require only the conceptual information from the designer, for the analysis and design of structures. These programs generally consist of three modules.

(i) The Preprocessor
(ii) The Analysis module
(iii) The Postprocessor module
(iv) The Design module

3.2 PREPROCESSOR:

Preprocessor is a computer program preceding the main program, which takes the basic minimum variables from the designer, and generates the configuration and geometry of the structure. It is used to feed the Analysis program, this saves the designer a lot of time and effort required in preparing huge data for the program, and avoids the chances of committing mistakes which generally creep in large inputs. This also saves computer time since repeated trials are not required for correcting the mistakes in the inputs.

In the present case a preprocessor for the generation of Free Standing Square Towers has been developed. The

basic information is fed to the preprocessor through a file, the interactive mode has deliberately been avoided, since there are a lot of Engineering decisions to be taken in the analysis and design . These are difficult to take sitting in front of the terminal. Further feeding the information interactively increases the dime for feeding the input to the program. Also if some mistake has been committed somewhere in the input it becomes difficult to rectify it, and the whole or a part of the input has to be fed again. The preprocessor that is named as TOWGEN is used to génerate the geometry of the tower by taking the basic information of the dimensions and the configurations of each of the panels. Four types of panels have been identified for a free standing tower, which can be assembled in a required sequence to generate almost all the towers of the present class. The four configurations are: (Fig. 3.1,3.2)

(a) **XX** : This consists of four columns at the four corners of the panel and eight inclined braces arranged in a form so as to roughly form an X in elevation.

(b) **XB** : This is sometimes also called as tension bracing and is very similar to the XX bracing the only difference being that four horizontal members have been added.

(c) **KK** : This bracing somewhat resembles the letter K in elevation, hence the name . This consists of four columns, eight inclined braces, eight horizontal members and four interplanar braces.

(d) AK : This bracing is used for tall towers, when the panel size is large. This bracing provides an advantage of more headway below the tower which may sometimes become useful. This bracing consists of four columns, twenty four inclined braces, eight horizontal braces and four interplanar braces.

The members have been divided into five types:

(a) COL : These are the corner members of the tower and are the most critical members in design as the load is transferred through the columns or legs to the foundation.

(b) XBRC : These are the inclined braces on all the four sides of the tower.

(c) TRAN : These are the horizontal or transverse members in plane with the Xbraces.

(d) SBRC : These are the interplanar horizontal members.

(e) KBRC : These are the inclined braces other than Xbraces in AK configuration.

For towers where the panel height is large the slenderness ratio of the columns becomes very large resulting in very heavy sections. To reduce the slenderness ratio of columns and braces some secondary braces are provided. Two schemes of secondary braces have been chosen (Fig. 3.3). These can be generated easily by specifying the number of subpanels to be generated in each of the cases.

A configuration file CONFIG.INP is required by TOWGEN and TOWER. This is a direct access file from which the configuration data of the four configurations are read.

This file is created by the program CONF which reads the data from a permanent file CONF.INP and writes a direct access file CONFIG.INP .

A program for manipulations of data from a data base of sections to select or deselect a particular section that is available for the analysis and design of tower has also been developed and named DATMAN. The sectional properties of the database are kept in a file SECTON.REC. For choosing any sectional property only the number of the sectional property need be given and the program selects the section property and writes in the file PROPS.INP which is used by the program. The program has been made completely menu driven .The program has the facility to add of substract some data form the actual database. The program consists of a main program and a subroutine used to sort the data of the sectional properties in ascending order of their areas for use by the design module. The units used in the database are mm and cm as given in SP16. The corresponding scale factors are given at the top of the database and can be changed to suit to the database in which the designer is working. This helps in saving a considerable amount of time of the designer as the sectional properties are not required to be typed for each problem they can be easily chosen from the ready database also since a separate file contains the sectional properties the designer can use the same database for more than one problem if the sections available are not

changing for the them, thus saving time of the designer.

Brief description of the Preprocessor:

Name of the Program	:	TOWGEN
Program Size	:	800 lines
Subroutines	:	5
Input File	:	1) Variable 7 Characters
		2) CONFIG.INP] Permanent
		3) PROPS.INP] files
Interface File	:	SPACE.INP
Output File	:	SECBRA.DAT

SUBROUTINES:

(1) **XX** :The subroutine generates XX or XB configurations.

(2) **KK** : The subroutine generates KK type of configuration.

(3) **AK** :The subroutine generates AK type of configuration.

(4) SBRC1 :This subroutine generates the secondary bracings of the first type (Fig. 3.3a).

(5) SBRC2 :This subroutine generates the secondary bracings of the second type (Fig. 3.3b).

3.3 ANALYSIS AND DESIGN

This is the portion of the computer program which processes the data generated by the Preprocessor, it generates the load based on the information provided by the user. The program then analyses the structure and calculates the member forces for each of the load cases. The post processing starts after this and only the the forces affecting the design of structure are picked up and the structure is designed. The results are output in a form that is understandable by the designer as well as the site Engineer at the construction site, and no further processing of the output is generally necessary, thus saving considerable amount of time and effort.

In the present case the main program TOWER has been interfaced with the help of an unformatted file SPACE.INP crated by TOWGEN. It requires some more information as regards the generation of loads the load combinations like extra loads to be added, and some other relevant design information about the material properties etc.

The program checks the input data and points out if there are any logical anomalies in the input. There are three modes of execution, depending on the selection of the mode of execution the program (i)Checks the data; (ii)Executes the program updating the analysis and design files in each iteration; (iii) Executes the program by adding to the analysis and design files all the data of each of the iterations respectively. There is full control of the designer over the flow of the program and he has the option of choosing the number of iterations and the maximum number of changes in the section so as to describe the convergence of the problem. The program generates the dead loads and the wind loads as opted by the user for each basic load combination . An advantage offered by the program is the number of basic load combinations is unlimited without the increase in core memory. This results in lesser executions of the program and lesser manual postprocessing, which saves a considerable amount of time of the design Engineer.

The tower is modeled as a Space Frame and analyzed by the direct stiffness method. The frontal technique has

been employed for the solution of the problem, the displacements and support reactions are calculated. The member forces are the calculated and stored in a disk file as a direct access file later use. The load vector and other variables are then initialized and the member forces are computed for the other load similarly. After all the loads have been completed the program control shifts towards the post processor section. Here superimposition technique is used to calculate the member forces for the load cases. The maximum compressive and tensile forces are picked up from all the loads and load cases for the design. The members are designed as axial load resisting members according to the recommendations of IS: 800-1984. If the number of sections changed (upgraded or downgraded) are more than the maximum permitted by the designer the analysis and design procedures are repeated again. The user has the option to choose between a theoretical design and a rational design, the theoretical being that the section properties of the sections columns being changed in each of the panels. The other option with the user is to specify the minimum sections that may be acceptable from the practical point of view. It is sometimes also not advisable to change the section of the columns in each panel as the columns have to be lapped to make a joint which requires a sufficient length of overlap, hence it may become sometimes advisable to continue the section of the columns upto three or four panels, although this may not be feasible from the theoretical point of view but is

a practical solution hence a fabrication length is required by the program and depending on this fabrication length it assigns the member properties of the columns in each of the panels. A sample design output is given in appendix

A Brief Description of The Program:

Name of the Program	:	TOWER
Program Size	:	2200 lines
No. of Subroutines	:	15
Input Files	:	1)Variable name 7characters (input file) 2)SPACE.INP (Interface file) 3)SPACE.INP Permanent 4)PROPS.INP files
Output Files	:	1)Variable 6 characters (Analysis file) 2)Variable 6 characters (Design file)

SUBROUTINES

(1) GOMTRY : This subroutine is reads the basic geometry of the tower and assign the member and material properties to the members of the tower.

(2) CHECK :This subroutine checks the input data logically for any anomalies and calculates the front width.

(3) MSTIFF : This subroutine assembles the stiffness and rotation transformation matrices for space truss and space frame members depending on the options given by the user.

(4) LOADIN :This subroutine reads the information about the loads on the tower and generates the dead and wind loads on the tower, depending on the codes for the direction of the wind loads it applies the wind diagonal as well as wind perpendicular to the structure.

(5) NODLOD : This subroutine is used to convert the nodal loads to the member loads in the global directions and viceversa.

(6) FRONT : This subroutine is used for the solution of the equations to give the displacements and the support reactions.

(7) OUTP1 : This subroutine prints out the loads and displacements of the structure.

(8) MFORC : This subroutine calculates the member forces in the member directions. It also selectively writes the member forces in a disk file for use later.

(9) XLCOMB : This subroutine outputs the member forces for the basic load combinations and calculates member forces in each of the load cases by superimposition. It also calculates the maximum compressive and tensile stresses for each member type in each panel for design.

(10) DESIN :This subroutine rationally designs the members of the tower based on the stress ratio of each type of members and practical considerations mentioned before. The total number of section changes are recorded and if more than the maximum permitted are made the tower is re-analyzed.

(11) DEDLOD : This subroutine is used to calculate the self weight of the tower members and the self weight of the secondary braces.

(12) SWIND : This subroutine calculates the wind loads for the wind blowing perpendicular to the face and from a

corner based on the procedure given in chapter 2.

(13) **AK2COF** : This subroutine calculates the coefficient K_2 depending on the terrain category of the structure and the class of the structure for each of its panels.

(14) CF : This subroutine calculates the factor C_f as described in chapter 2.

(15) ITPLT : This subroutine is used for interpolation of data from the tables recommended by Indian Standards.

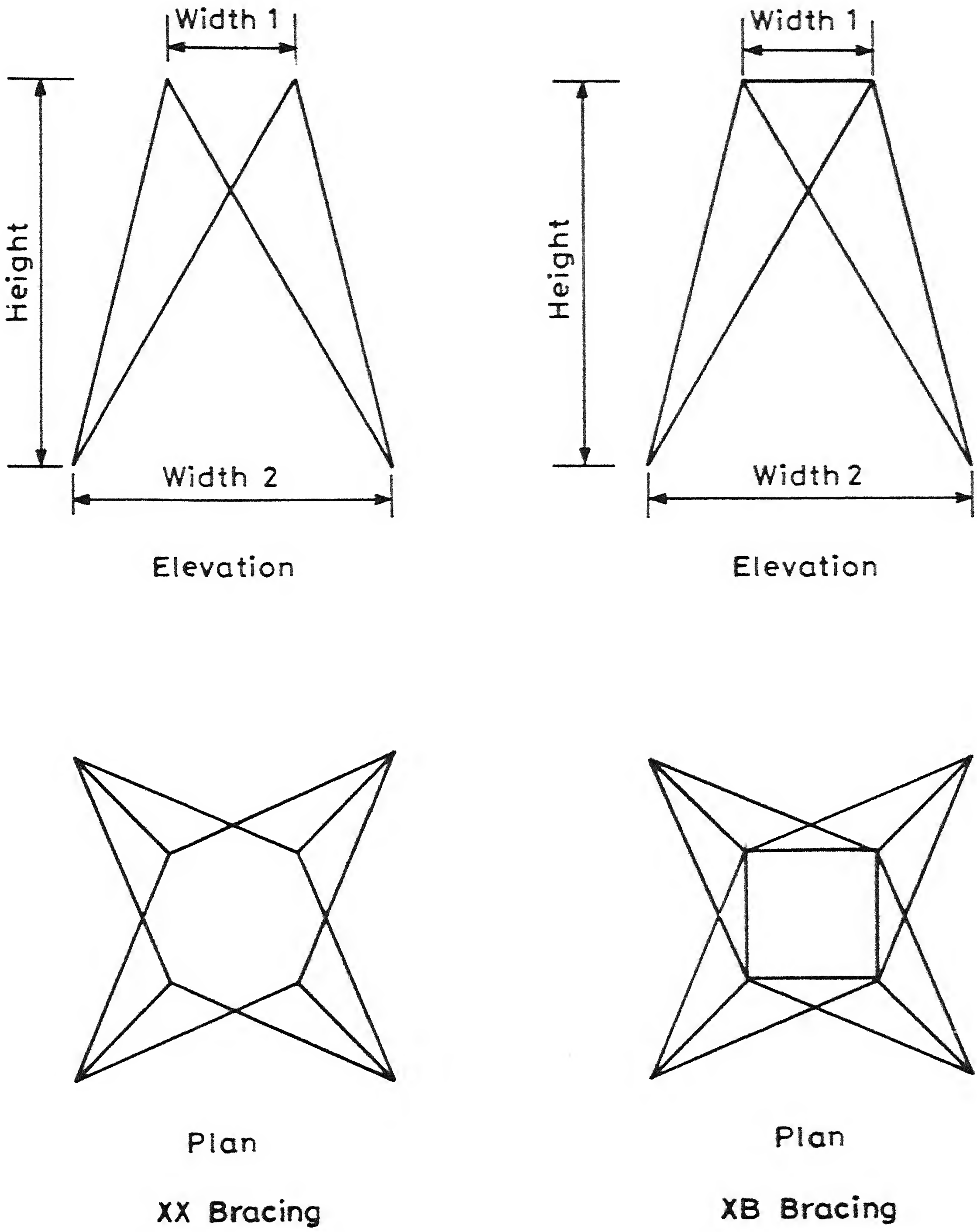


Fig. 3.1 Types of panel configuration.

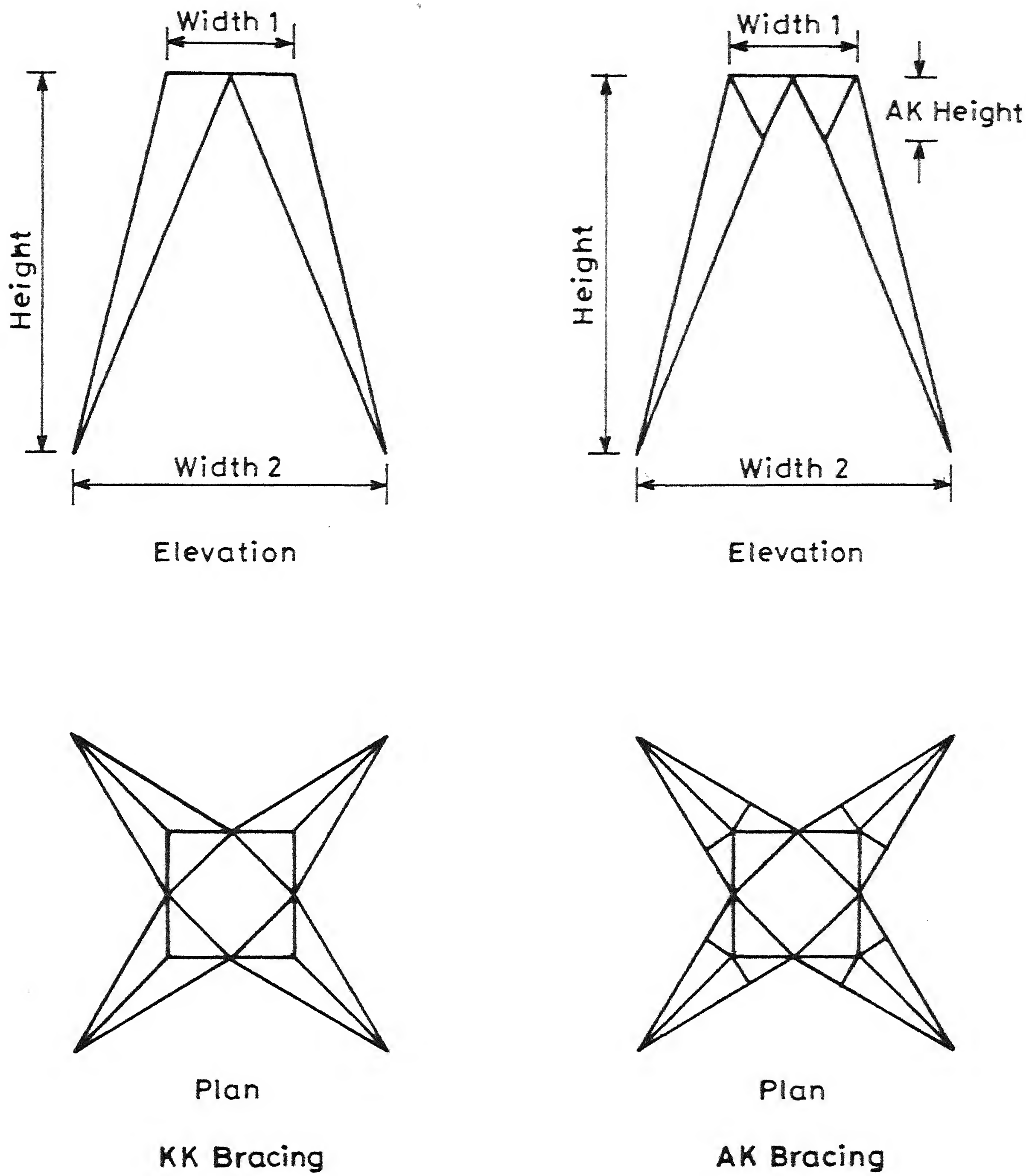


Fig. 3.2 Types of panel configuration.

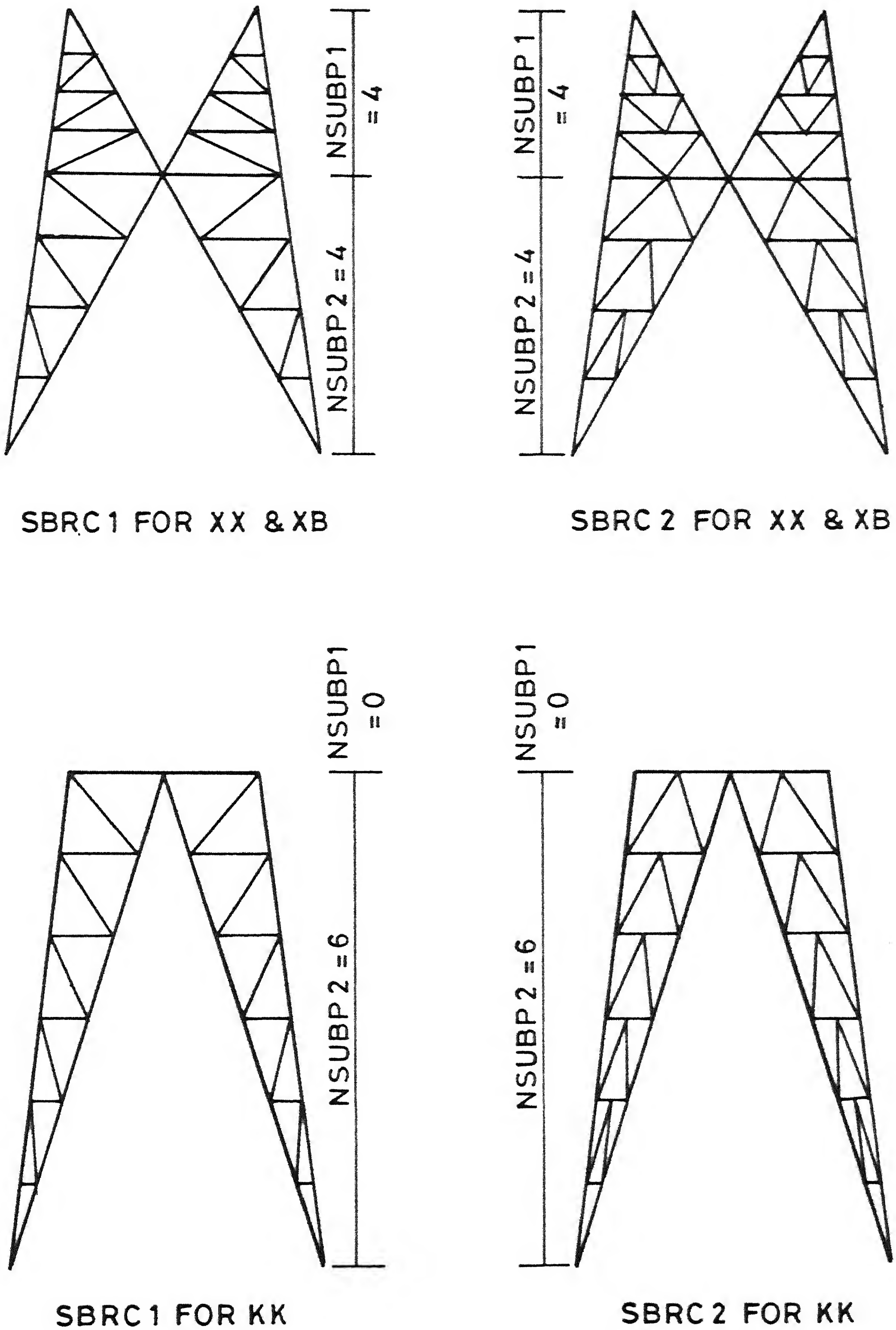


Fig. 3.3 Arrangement of secondary braces in panels.

CHAPTER IV

RESULTS AND DISCUSSIONS

4.1 GENERAL:

Weight of a tower is observed to be the most dominant factor governing the cost of a tower as discussed in 1.3. Hence weight has been taken as the objective function, and the effect of variation of some other parameters like the base width, configuration of the tower and the number of panels was studied. The package described in the previous chapters has been used for the study. A 50m tower has been selected for case analysis and the effect of the variable parameters is studied. The wind velocity is assumed to be 47m/s and the terrain category as 1. A database of 64 sections and properties generally used in practice is made available to the program. To study the effect of height of tower on the weight, four towers of height 50m, 75m, 100m and 125m were taken. All the towers were analyzed for three basic loads, i.e. dead load, wind load (perp. to face) and wind load (diagonal) respectively. Two load combinations were obtained by the superimposition of the basic loads i.e. dead load+wind load (perp. to face) and dead load+wind load (diagonal). Four 4m antennae were assumed to be mounted on the tower with a solidity ratio of 0.4.

4.2 PARAMETRIC STUDY:

The effect of various parameters on weight as mentioned in 4.1 were studied for a 50m tower. The study was carried out by taking the tower with three base widths of 5m, 6.25m and 8m respectively. The number of panels were varied as 16,20 and 24, each of the cases was analyzed and designed for four configurations.

(i) 0 XX + Full KK
(ii) 1/3 XX + 2/3 KK
(iii) 2/3 XX + 1/3 KK
(iv) Full XX + 0 KK

The effect of the various parameters is discussed below.

n.b. 1/3 XX + 2/3 KK means top 1/3 is XX braced and bottom 2/3 is KK braced.

4.2.1 Effect of Base width on Weight:

The base width of the tower is a very important factor, since the weight of columns is approximately inversely proportional to the base width of the tower, but if the base width is increase abnormally the weight of columns loose their prominence and the weight of other members also starts contributing significantly, hence the overall weight of the tower does not decease further. This trend can be observed from (Fig. 4.2). It can be seen that some of the curves are approaching a zero slope to achieve the optimum weight. The curves 1.3 and 2.4 have their optimum at a base width of 5.5m approximately.

4.2.2 Effect of Number of Panels on Weight:

Generally as the number of panels go on increasing, the weight of the tower also increases because extra horizontal and inter planar braces are added and a marginal economy achieved in the weight of the columns is compensated, but as can be seen from (Fig. 4.3) in case of XX panel configuration the weight of the tower seems to have a maximum at about 20 panels this is probably because the XX configuration does not have horizontal members and interplanar braces, with the result economy achieved in column weights is preserved and the overall weight decreases. If the number of panels is increased the weight of secondary braces decreases because the size of each panel reduces hence affecting the slenderness ratio and the secondary braces.

4.2.3 Effect of Configuration on Weight:

A general trend as concluded from (Fig. 4.2) is, as the number of panels with KK configuration increases the weight of the tower increases. This is primarily because horizontal and interplanar braces are added when the KK configuration is used thereby increasing the weight of the tower. However it can be seen that at about 7.5m base width the curves 2.3 &2.4 and 3.2&3.3 intersect this may be because the small amount of reduction in weight due to XX bracing is compensated by the increase in column and X brace weight.

4.2.4 Effect of Height on Weight:

The study of this parameter is carried out by taking a 125m tower and then truncating it at 100m, 75m and 50m levels. It is seen from (Fig.4.4) that the weight of the tower increases very rapidly as the height of the tower. The total weight of the tower an columns follow roughly a power law of exponent 1.15 for towers upto 100m height and then 1.085 for 125m tower. The weight of horizontal members and inclined braces also increases as the height. The variation of weight of interplanar braces is linear.

4.3 CONCLUSIONS:

In study of towers the following general observations were made:

(1) The wind forces increase with the height of the tower as concluded from (Fig.4.6,4.7). The leg forces also follow the same profile.

(2) The deflection profile is that of a laterally loaded cantilever.

(3) The total weight of the tower consists of approximately

Weight of Columns	:45 to 65%
Weight of Inclined braces	:16 to 25%
Weight of Horizontal braces	:0 to 15%
Weight of Interplanar braces	:0 to 5%
Weight of secondary braces	:5 to 20%

(4) The weight of the columns changes marginally with the change in configuration, but it changes significantly with changes in base width.

(5) The cross braces and horizontal members primarily

resist shear and hence are of nominal size unless the panel size is very large.

(6) Interplanar braces are of nominal sizes and have virtually no forces they are provided to impart rigidity to the tower.

(7) The columns are normally critical when the wind is blowing from the corner of the tower.

(8) The inclined braces are critical when the wind is blowing perpendicular to the face.

(9) The weight of the tower increases geometrically as the height and the exponent is between 1.07 and 1.16 for every 25m increase in the tower height.

(10) As seen from (Fig.4.5) if the tower is designed by a rationalized approach the weight of the tower increases by about 10% but the saving in steel due to lapping may overcome this advantage, and these towers may actually prove to be costlier than rationalized towers on construction.

It can be concluded that the design of free standing towers can be Automated completely, so that with only a few statements input the whole tower can be generated, the loads calculated according to the recommendations of the code and analyze and design of the tower may be achieved with a minimum effort and time. In future the dynamic analysis of wind coupled with secondary analysis of the tower can be incorporated to give a better insight to the actual behavior of tower to wind loads.

VARIATION OF WEIGHT OF MEMBERS OF TOWER FOR DIFFERENT BASEWIDTHS,NUMBER OF PANELS AND BRACING TYPE

WEIGHT	16 PANELS				20 PANELS				24 PANELS			
	FULL AA	2/3 AA	1/3 AA	FULL XX	FULL AA	2/3 AA	1/3 AA	FULL XX	FULL AA	2/3 AA	1/3 AA	FULL XX
8m BASE WIDTH												
TOTAL	92.80	93.20	93.80	94.00	91.80	91.40	91.50	96.20	97.90	96.90	97.90	105.0
COLS	47.50	46.80	48.80	48.30	46.50	47.40	47.30	48.20	46.00	46.30	47.00	47.30
XBRC	17.30	15.30	17.30	20.90	21.60	21.10	21.90	33.20	22.40	22.90	24.20	28.40
TRAN	9.01	8.56	6.50	0.08	11.70	10.90	8.77	0.08	15.30	14.30	11.40	0.08
SBRC	3.91	3.53	2.19	0.00	5.06	4.43	3.02	0.00	6.12	5.41	3.54	0.00
SECBRA	15.10	19.10	19.10	24.70	6.99	7.64	10.50	14.80	8.00	8.00	11.90	28.80
6.25m BASE WIDTH												
TOTAL	93.90	94.40	93.30	93.40	93.50	92.60	91.90	93.40	97.10	96.20	95.90	98.80
COLS	52.90	53.20	54.40	54.90	55.10	55.80	56.10	56.80	54.80	55.30	55.30	56.40
XBRC	18.60	16.10	16.60	18.20	20.20	19.40	18.70	24.70	20.40	20.50	20.80	23.00
TRAN	6.60	6.18	4.49	0.08	8.21	7.48	5.86	0.08	10.40	9.55	7.27	0.08
SBRC	3.18	2.83	1.73	0.00	4.11	3.54	2.39	0.00	4.97	4.32	3.79	0.00
SECBRA	12.70	16.10	16.00	20.20	5.86	6.45	8.80	11.90	6.37	6.57	9.69	19.30
5m BASE WIDTH												
TOTAL	98.20	98.90	97.60	99.70	97.90	97.20	96.20	97.20	99.90	101.0	99.90	106.0
COLS	61.40	61.60	62.90	65.80	62.70	63.80	64.10	65.10	63.00	64.60	64.50	66.10
XBRC	18.20	16.30	16.10	16.70	20.40	17.30	18.20	22.10	19.60	20.10	19.80	20.50
TRAN	4.97	4.58	3.26	0.08	6.28	5.60	4.24	0.08	7.63	6.94	5.14	0.08
SBRC	2.67	2.33	1.40	0.00	3.43	2.90	1.93	0.00	4.15	3.54	2.26	0.00
SECBRA	11.10	14.00	13.90	17.10	5.07	5.63	7.63	9.84	5.57	5.57	8.18	19.0

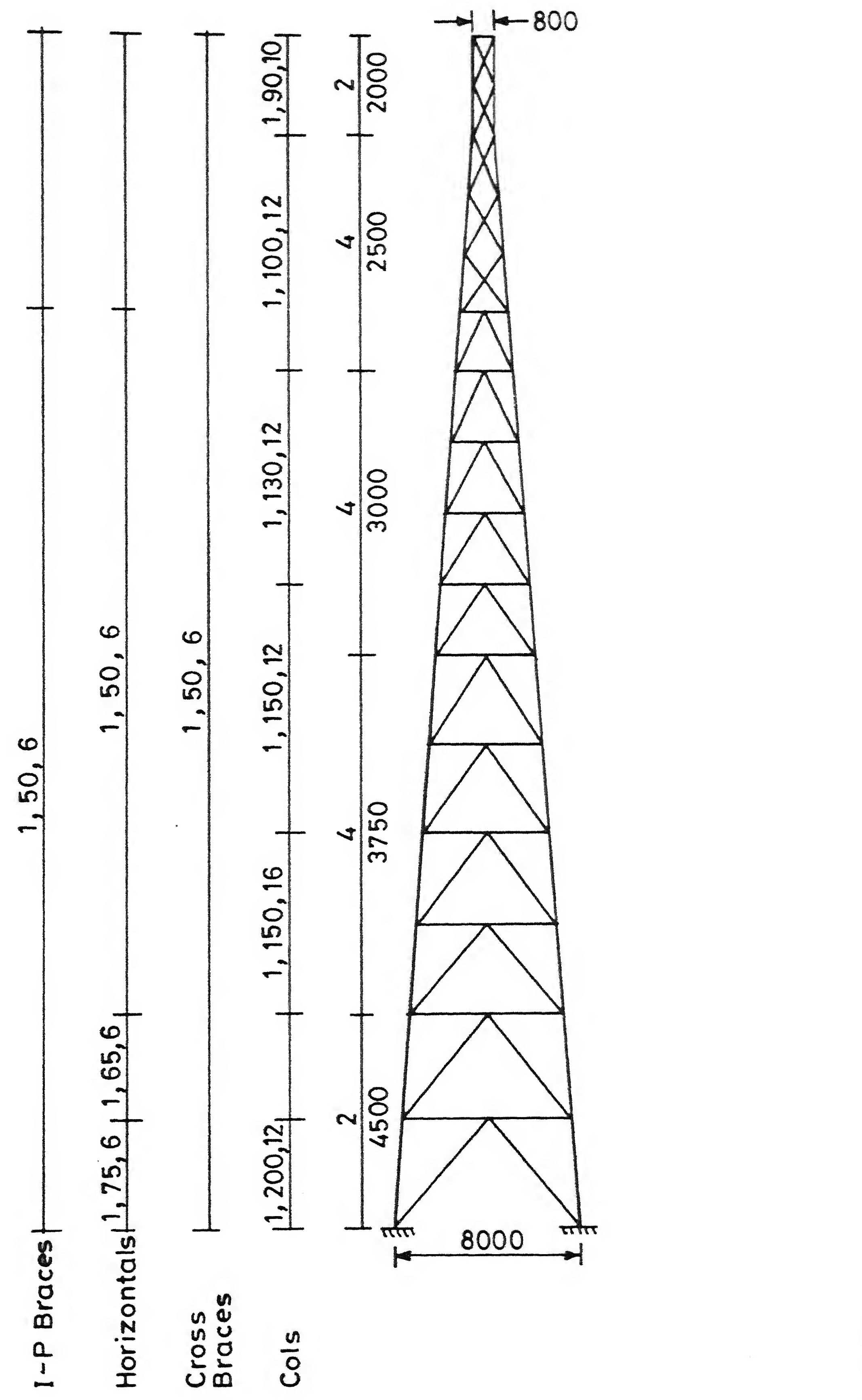


Fig.4.1 50m tower with 16 panels, 2/3 KK, 8m width.

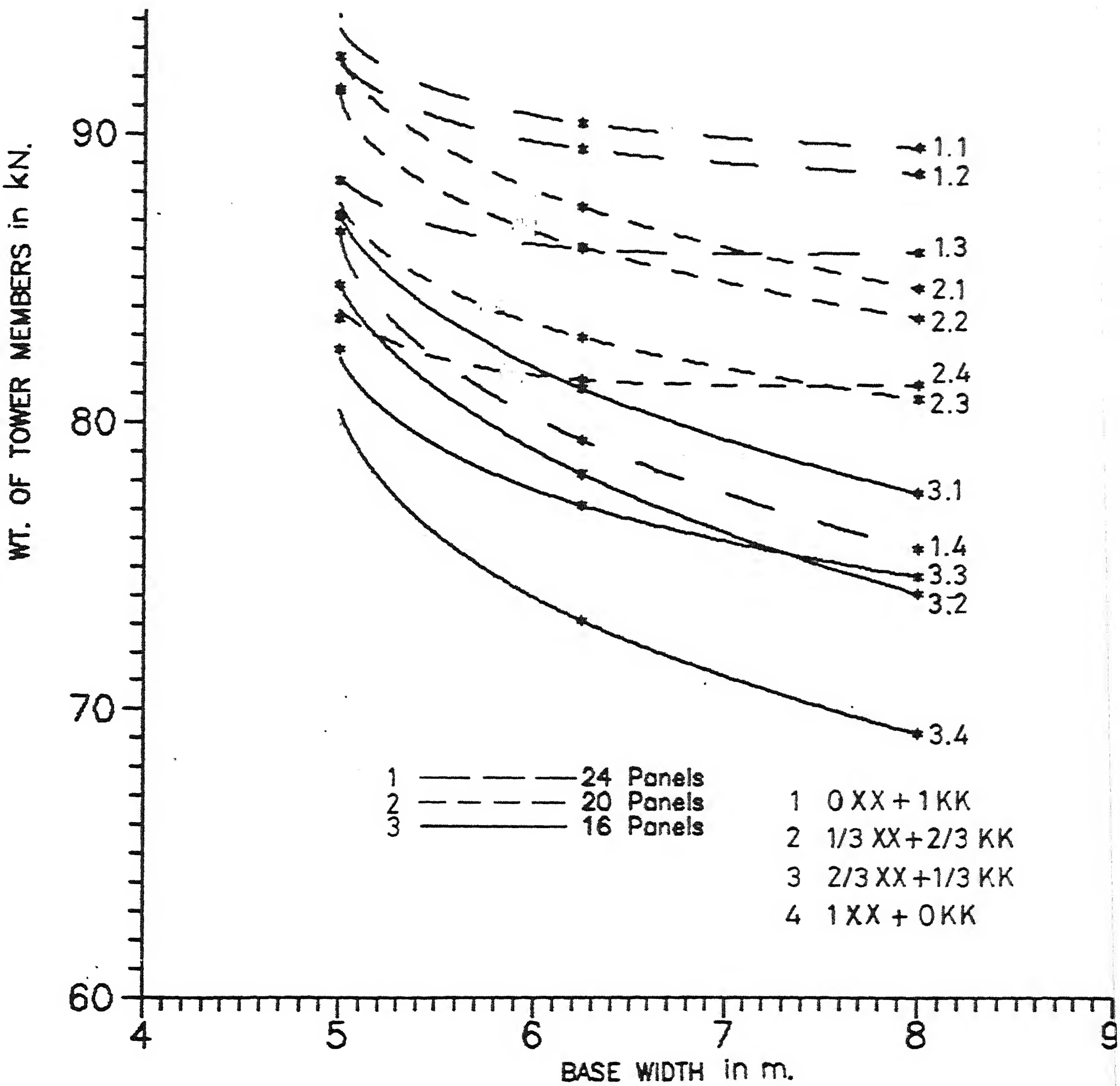


Fig. 4.2 Variation of weight with base width.

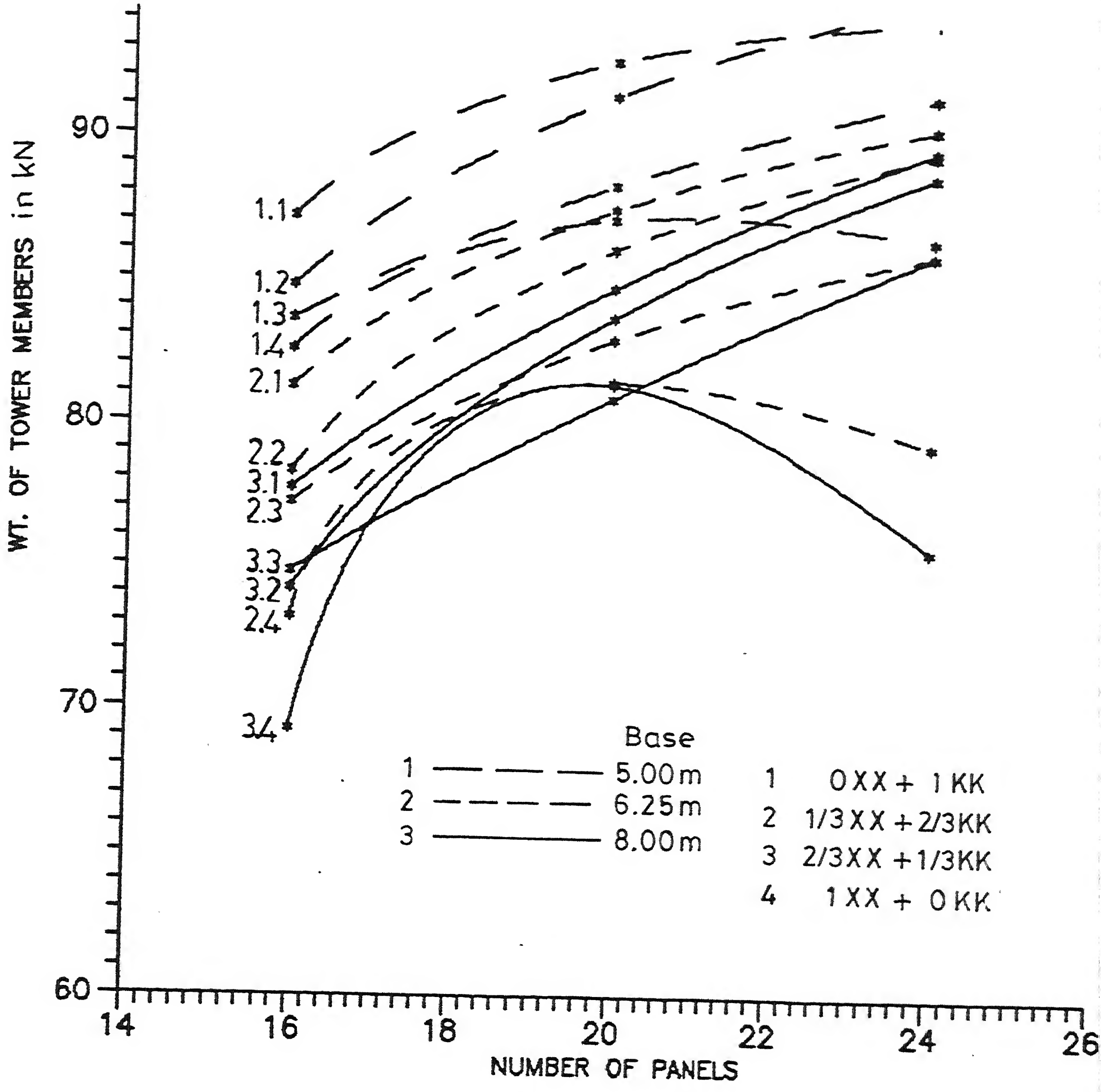


Fig. 4.3 Variation of weight with number of panels.

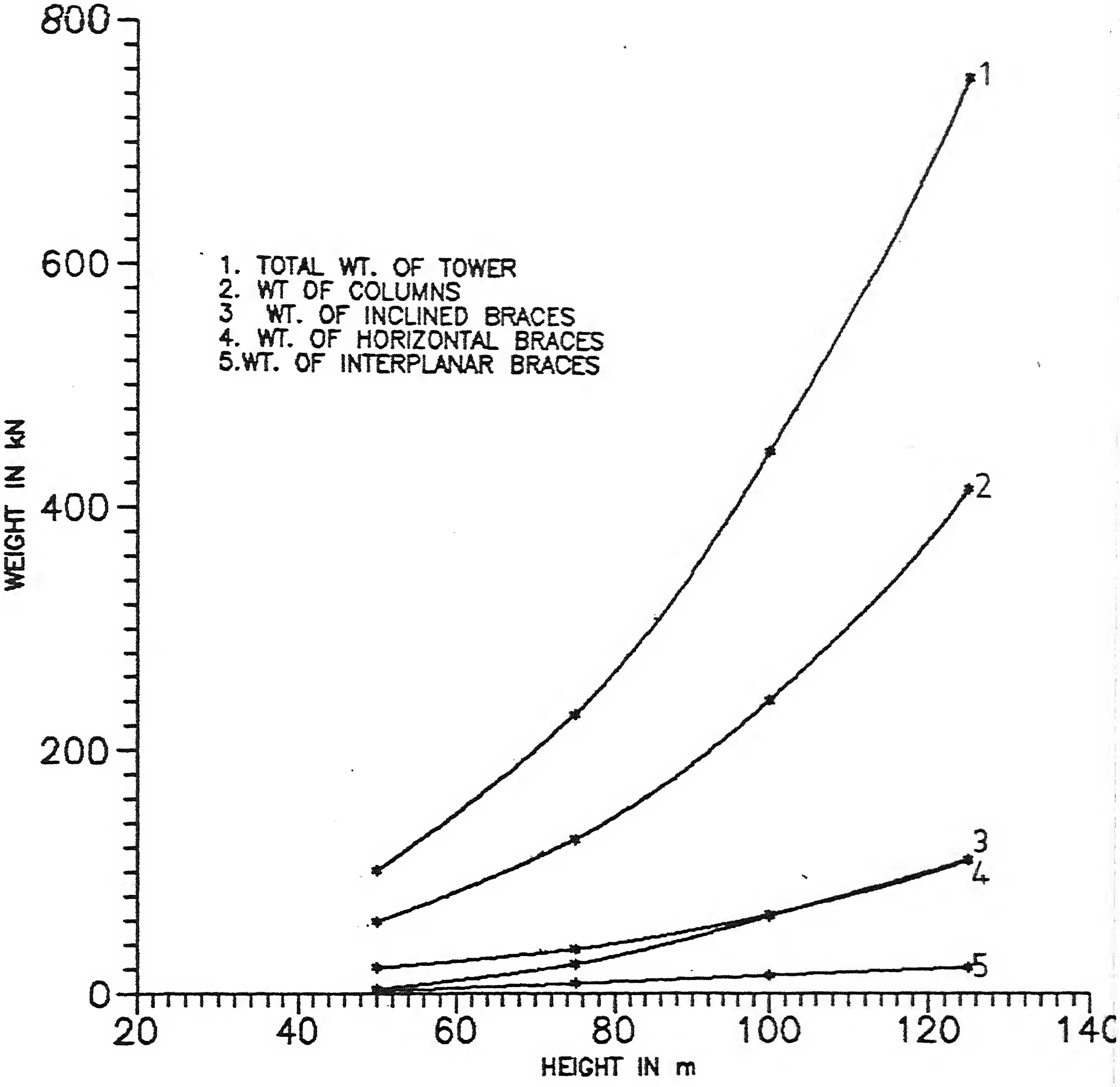


Fig. 4.4 Variation of weight with height of tower

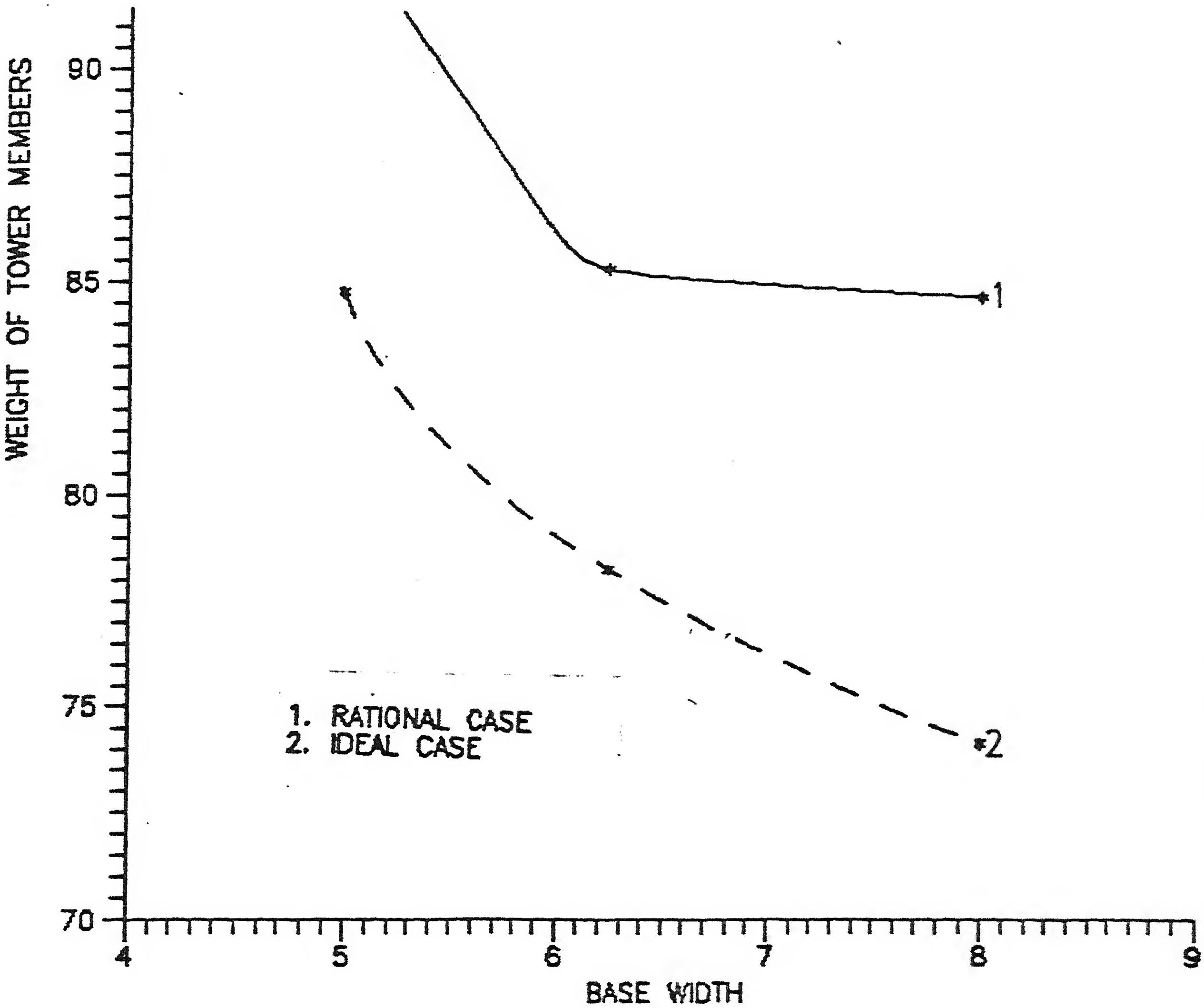


Fig. 4.5 Variation of weight with base width.

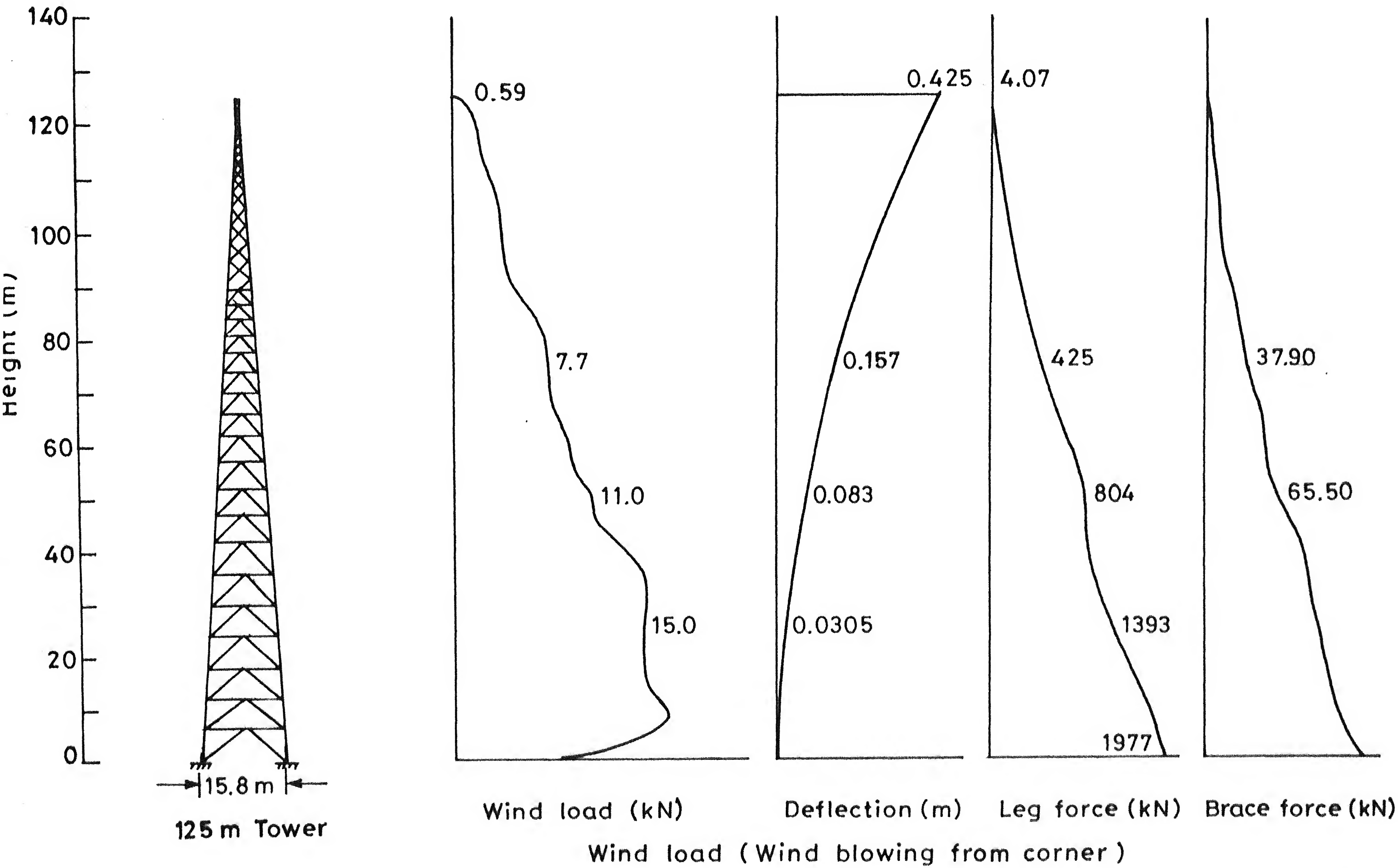


Fig. 4.6 Variation of wind load and forces along the height.

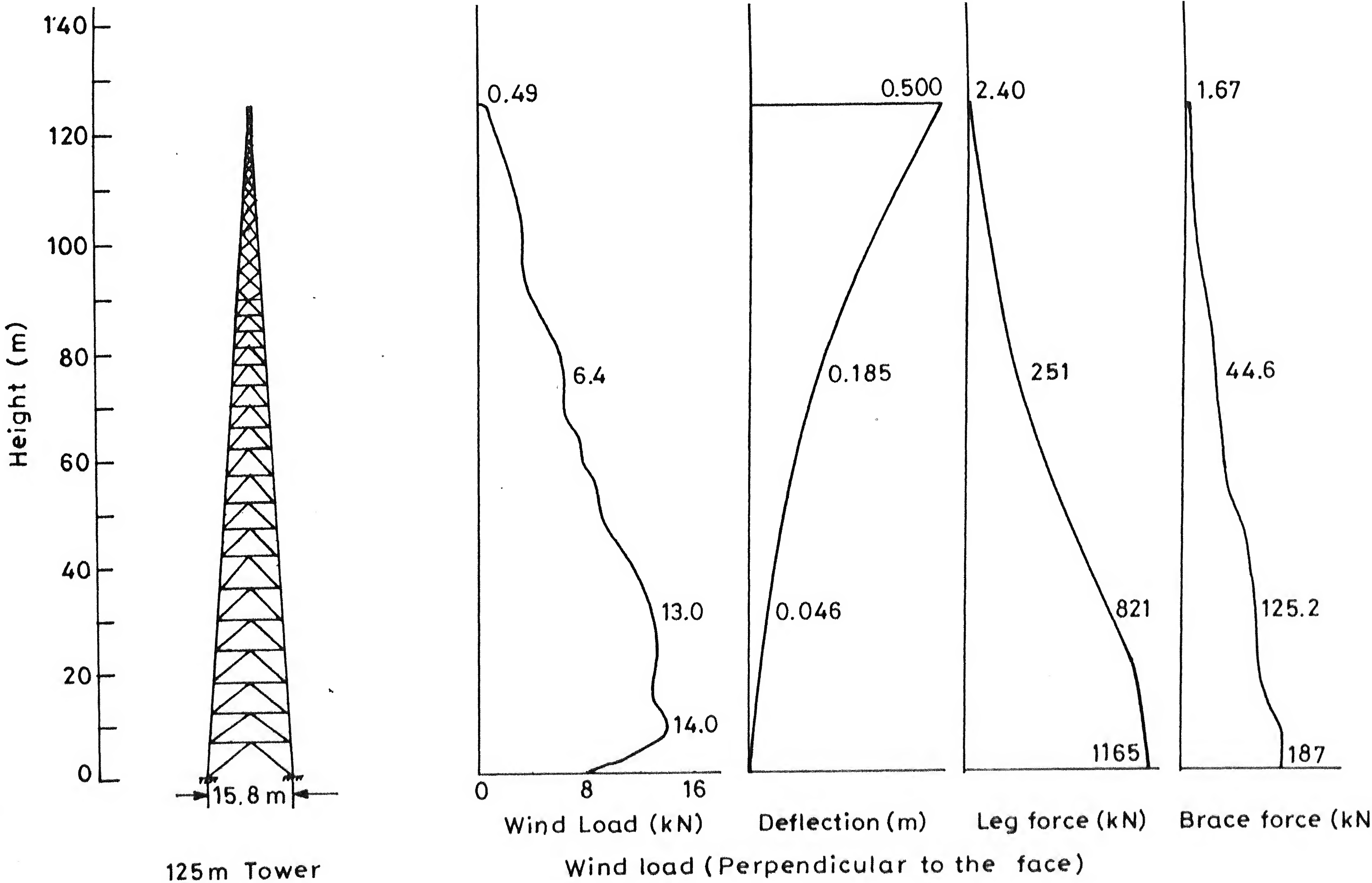


Fig. 4.7 Variation of wind load and forces along the height.

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19. Indian Standard Codes Used:

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b: IS 800-1984 Code of Practice for General Construction in Steel.

c: SP:6 ISI Handbook for Structural Engineers part 1.

APPENDIX

A 125M TOWER WITH 29 PANELS AND 15.8M NO ANTENNA

****

GENERAL ANALYSIS INFORMATION FOR THE TOWER

^^

THE UNITS ARE IN N & m UNLESS OTHERWISE CHANGED

****

1: MEMBERS . . . .= 580

2: NODES IN THE TOWER . . . .= 196

3: NUMBER OF MATERIALS USED . . . .= 1

4: NUMBER OF BASIC LOAD CASES . . . .= 3

5: NUMBER OF LOAD COMBINATIONS. . . . .= 2

6: SCALE FACTOR FOR DISTANCES wrt mts.. . . . .= 1.00

7: SCALE FACTOR FOR FORCES wrt Newtons. . . .= .100E-02

8: RIVET NOMINAL DIAMETER . . . .= .0160

9: MAXIMUM NO. OF ITERATIONS. . . . .= 7

10: MAXIMUM NO. OF MEM CHANGES . . . .= 2

9: MODE OF EXECUTION (0=Data Check. . . . . . .= 1
1=Execution 2=Execution Output all Iteratios)

THE PROPERTIES OF THE MATERIALS USED(N/m2,m)

^^^

MATNO:	YOUNG S MODULUS	SHEAR MODULUS	SPWT	Fy
1	.21000E+09	.10000E+09	.785000E+02	.25000E+06

				MAIN MEMBER INFORMATION										SEC-MEM INFO				
				Material					Member									
Pnl	Width	Height	TYP	Col	Xbr	Hor	Sbr	Kbr	Col	Xbr	Hor	Sbr	Kbr	Mat	Mem	Typ	Sp1	Sp2
1	.800	2.50	XB	1	1	1	0	0	8	5	5	0	0	1	1	1	1	1
2	.800	2.50	XX	1	1	0	0	0	8	5	0	0	0	1	1	1	1	1
3	.800	3.50	XX	1	1	0	0	0	15	5	0	0	0	1	1	1	2	1
4	1.24	3.50	XX	1	1	0	0	0	15	5	0	0	0	1	1	1	2	1
5	1.68	3.50	XX	1	1	0	0	0	15	5	0	0	0	1	1	1	2	1
6	2.11	3.50	XX	1	1	0	0	0	21	5	0	0	0	1	1	1	2	1
7	2.55	3.75	XX	1	1	0	0	0	21	5	0	0	0	1	1	1	2	1
8	3.02	3.75	XX	1	1	0	0	0	21	5	0	0	0	1	1	1	2	1
9	3.49	3.75	XX	1	1	0	0	0	25	5	0	0	0	1	1	1	2	1
10	3.96	3.75	XX	1	1	0	0	0	25	5	0	0	0	1	1	1	2	1
11	4.43	4.00	KK	1	1	1	1	0	25	5	5	5	0	1	1	1	0	3
12	4.93	4.00	KK	1	1	1	1	0	26	5	5	5	0	1	1	1	0	3
13	5.43	4.00	KK	1	1	1	1	0	26	5	6	5	0	1	1	1	0	3
14	5.93	4.00	KK	1	1	1	1	0	30	5	7	5	0	1	1	1	0	3
15	6.43	4.00	KK	1	1	1	1	0	30	5	9	5	0	1	1	1	0	3
16	6.93	4.00	KK	1	1	1	1	0	39	6	9	5	0	1	1	1	0	3
17	7.43	4.25	KK	1	1	1	1	0	39	6	10	5	0	1	1	1	0	4
18	7.96	4.25	KK	1	1	1	1	0	43	6	12	5	0	1	1	1	0	4
19	8.49	4.25	KK	1	1	1	1	0	43	7	12	5	0	1	1	1	0	4
20	9.02	4.25	KK	1	1	1	1	0	47	7	13	5	0	1	1	1	0	4
21	9.55	4.25	KK	1	1	1	1	0	47	8	16	5	0	1	1	1	0	4
22	10.1	4.25	KK	1	1	1	1	0	51	8	17	5	0	1	1	1	0	4
23	10.6	5.50	KK	1	1	1	1	0	51	10	21	5	0	1	1	1	0	5
24	11.3	5.50	KK	1	1	1	1	0	53	10	21	5	0	1	1	1	0	5
25	12.0	5.50	KK	1	1	1	1	0	53	11	22	5	0	1	1	1	0	5
26	12.7	5.50	KK	1	1	1	1	0	55	11	23	5	0	1	1	1	0	5
27	13.4	5.50	KK	1	1	1	1	0	55	11	23	5	0	1	1	1	0	5
28	14.0	5.50	KK	1	1	1	1	0	58	12	24	5	0	1	1	1	0	5
29	14.7	8.50	KK	1	1	1	1	0	58	15	25	5	0	1	1	1	0	7
	15.8																	

Pnl	Typ	Mpr	Lnt	Area cm2	Ixx cm4	Iyy cm4	Rmin cm		S I Z E mm	mm	mm	Arrn	No
1	COL	1	2.500	9.29	56.0	56.0	1.56	ISA	80.	80.	6.	SNGL	1.
1	XBRC	1	2.625	5.68	12.9	12.9	.97	ISA	50.	50.	6.	SNGL	1.
1	TRAN	1	.800	5.68	12.9	12.9	.97	ISA	50.	50.	6.	SNGL	1.
2	COL	1	2.500	9.29	56.0	56.0	1.56	ISA	80.	80.	6.	SNGL	1.
2	XBRC	1	2.625	5.68	12.9	12.9	.97	ISA	50.	50.	6.	SNGL	1.
3	COL	1	3.514	19.03	177.0	177.0	1.94	ISA	100.	100.	10.	SNGL	1.
3	XBRC	1	3.652	5.68	12.9	12.9	.97	ISA	50.	50.	6.	SNGL	1.
4	COL	1	3.514	19.03	177.0	177.0	1.94	ISA	100.	100.	10.	SNGL	1.
4	XBRC	1	3.799	5.68	12.9	12.9	.97	ISA	50.	50.	6.	SNGL	1.
5	COL	1	3.513	19.03	177.0	177.0	1.94	ISA	100.	100.	10.	SNGL	1.
5	XBRC	1	3.986	5.68	12.9	12.9	.97	ISA	50.	50.	6.	SNGL	1.
6	COL	1	3.514	25.12	405.3	405.3	2.57	ISA	130.	130.	10.	SNGL	1.
6	XBRC	1	4.210	5.68	12.9	12.9	.97	ISA	50.	50.	6.	SNGL	1.
7	COL	1	3.765	25.12	405.3	405.3	2.57	ISA	130.	130.	10.	SNGL	1.
7	XBRC	1	4.677	5.68	12.9	12.9	.97	ISA	50.	50.	6.	SNGL	1.
8	COL	1	3.765	25.12	405.3	405.3	2.57	ISA	130.	130.	10.	SNGL	1.
8	XBRC	1	4.971	5.68	12.9	12.9	.97	ISA	50.	50.	6.	SNGL	1.
9	COL	1	3.765	32.76	357.3	357.3	2.14	ISA	110.	110.	16.	SNGL	1.
9	XBRC	1	5.291	5.68	12.9	12.9	.97	ISA	50.	50.	6.	SNGL	1.
10	COL	1	3.765	32.76	357.3	357.3	2.14	ISA	110.	110.	16.	SNGL	1.
10	XBRC	1	5.632	5.68	12.9	12.9	.97	ISA	50.	50.	6.	SNGL	1.
11	COL	1	4.016	32.76	357.3	357.3	2.14	ISA	110.	110.	16.	SNGL	1.
11	XBRC	1	4.705	5.68	12.9	12.9	.97	ISA	50.	50.	6.	SNGL	1.
11	TRAN	1	2.215	5.68	12.9	12.9	.97	ISA	50.	50.	6.	SNGL	1.
11	SBRC	1	3.132	5.68	12.9	12.9	.97	ISA	50.	50.	6.	SNGL	1.
12	COL	1	4.016	34.16	701.0	701.0	4.28	ISA	110.	110.	8.	STAR	2.
12	XBRC	1	4.841	5.68	12.9	12.9	.97	ISA	50.	50.	6.	SNGL	1.
12	TRAN	1	2.465	5.68	12.9	12.9	.97	ISA	50.	50.	6.	SNGL	1.
12	SBRC	1	3.486	5.68	12.9	12.9	.97	ISA	50.	50.	6.	SNGL	1.
13	COL	1	4.016	34.16	701.0	701.0	4.28	ISA	110.	110.	8.	STAR	2.
13	XBRC	1	4.985	5.68	12.9	12.9	.97	ISA	50.	50.	6.	SNGL	1.
13	TRAN	1	2.715	7.44	29.1	29.1	1.26	ISA	65.	65.	6.	SNGL	1.
13	SBRC	1	3.840	5.68	12.9	12.9	.97	ISA	50.	50.	6.	SNGL	1.
14	COL	1	4.016	40.56	1158.9	1158.9	4.94	ISA	130.	130.	8.	STAR	2.
14	XBRC	1	5.138	5.68	12.9	12.9	.97	ISA	50.	50.	6.	SNGL	1.
14	TRAN	1	2.965	8.66	45.7	45.7	1.46	ISA	75.	75.	6.	SNGL	1.
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	.97	ISA	50.	50.	6.	SNGL	1.

Pnl	Typ	Mpr	Lnt	Area cm2	Ixx cm4	Iyy cm4	Rmin cm	S I Z E mm mm mm	Arrn	No
16	SBRC	1	4.900	5.68	12.9	12.9	.97	ISA 50. 50. 6.	SNGL	1.
17	COL	1	4.266	57.80	2197.7	2197.7	3.91	ISA 200.200.15.	SNGL	1.
17	XBRC	1	5.829	7.44	29.1	29.1	1.26	ISA 65. 65. 6.	SNGL	1.
17	TRAN	1	3.715	11.67	111.3	111.3	1.95	ISA 100.100. 6.	SNGL	1.
17	SBRC	1	5.254	5.68	12.9	12.9	.97	ISA 50. 50. 6.	SNGL	1.
18	COL	1	4.266	65.52	1436.8	1436.8	4.18	ISA 110.110.16.	STAR	2.
18	XBRC	1	6.013	7.44	29.1	29.1	1.26	ISA 65. 65. 6.	SNGL	1.
18	TRAN	1	3.980	17.03	126.7	126.7	1.74	ISA 90. 90.10.	SNGL	1.
18	SBRC	1	5.629	5.68	12.9	12.9	.97	ISA 50. 50. 6.	SNGL	1.
19	COL	1	4.266	65.52	1436.8	1436.8	4.18	ISA 110.110.16.	STAR	2.
19	XBRC	1	6.203	8.66	45.7	45.7	1.46	ISA 75. 75. 6.	SNGL	1.
19	TRAN	1	4.245	17.03	126.7	126.7	1.74	ISA 90. 90.10.	SNGL	1.
19	SBRC	1	6.003	5.68	12.9	12.9	.97	ISA 50. 50. 6.	SNGL	1.
20	COL	1	4.266	78.32	2361.0	2361.0	4.94	ISA 130.130.16.	STAR	2.
20	XBRC	1	6.398	8.66	45.7	45.7	1.46	ISA 75. 75. 6.	SNGL	1.
20	TRAN	1	4.510	17.08	196.8	196.8	2.18	ISA 110.110. 8.	SNGL	1.
20	SBRC	1	6.378	5.68	12.9	12.9	.97	ISA 50. 50. 6.	SNGL	1.
21	COL	1	4.266	78.32	2361.0	2361.0	4.94	ISA 130.130.16.	STAR	2.
21	XBRC	1	6.598	9.29	56.0	56.0	1.56	ISA 80. 80. 6.	SNGL	1.
21	TRAN	1	4.775	20.19	147.9	147.9	1.74	ISA 90. 90.12.	SNGL	1.
21	SBRC	1	6.753	5.68	12.9	12.9	.97	ISA 50. 50. 6.	SNGL	1.
22	COL	1	4.266	100.48	2916.2	2916.2	5.38	ISA 130.130.10.	STAR	4.
22	XBRC	1	6.803	9.29	56.0	56.0	1.56	ISA 80. 80. 6.	SNGL	1.
22	TRAN	1	5.040	20.28	331.0	331.0	2.59	ISA 130.130. 8.	SNGL	1.
22	SBRC	1	7.128	5.68	12.9	12.9	.97	ISA 50. 50. 6.	SNGL	1.
23	COL	1	5.522	100.48	2916.2	2916.2	5.38	ISA 130.130.10.	STAR	4.
23	XBRC	1	7.892	11.67	111.3	111.3	1.95	ISA 100.100. 6.	SNGL	1.
23	TRAN	1	5.305	25.12	405.3	405.3	2.57	ISA 130.130.10.	SNGL	1.
23	SBRC	1	7.502	5.68	12.9	12.9	.97	ISA 50. 50. 6.	SNGL	1.
24	COL	1	5.522	119.52	3515.4	3515.4	5.42	ISA 130.130.12.	STAR	4.
24	XBRC	1	8.143	11.67	111.3	111.3	1.95	ISA 100.100. 6.	SNGL	1.
24	TRAN	1	5.650	25.12	405.3	405.3	2.57	ISA 130.130.10.	SNGL	1.
24	SBRC	1	7.990	5.68	12.9	12.9	.97	ISA 50. 50. 6.	SNGL	1.
25	COL	1	5.522	119.52	3515.4	3515.4	5.42	ISA 130.130.12.	STAR	4.
25	XBRC	1	8.400	13.79	104.2	104.2	1.75	ISA 90. 90. 8.	SNGL	1.
25	TRAN	1	5.995	29.21	633.5	633.5	2.98	ISA 150.150.10.	SNGL	1.
25	SBRC	1	8.478	5.68	12.9	12.9	.97	ISA 50. 50. 6.	SNGL	1.
26	COL	1	5.521	139.08	5392.0	5392.0	6.23	ISA 150.150.12.	STAR	4.
26	XBRC	1	8.660	13.79	104.2	104.2	[illegible]	[illegible]	[illegible]	[illegible]

Pnl	Typ	Mpr	Lnt	Area cm2	Ixx cm4	Iyy cm4	Rmin cm		S I Z E mm mm mm	Arrn	No
28	COL	1	5.522	182.60	7227.6	7227.6	6.29	ISA	150.150.16.	STAR	4.
28	XBRC	1	9.202	17.03	126.7	126.7	1.74	ISA	90. 90.10.	SNGL	1.
28	TRAN	1	7.025	30.78	509.7	509.7	3.80	ISA	100.100. 8.	STAR	2.
28	SBRC	1	9.935	5.68	12.9	12.9	.97	ISA	50. 50. 6.	SNGL	1.
29	COL	1	8.533	182.60	7227.6	7227.6	6.29	ISA	150.150.16.	STAR	4.
29	XBRC	1	11.616	19.03	177.0	177.0	1.94	ISA	100.100.10.	SNGL	1.
29	TRAN	1	7.370	32.76	357.3	357.3	2.14	ISA	110.110.16.	SNGL	1.
29	SBRC	1	10.423	5.68	12.9	12.9	.97	ISA	50. 50. 6.	SNGL	1.

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TOTAL WEIGHT OF THE TOWER . . . . = 644.
TOTAL WEIGHT OF THE COLUMNS . . . . . . = 302.
TOTAL WEIGHT OF THE XBRACES . . . . . . = 104.
TOTAL WEIGHT OF THE HORIZONTALS . . . = 120.
TOTAL WEIGHT OF THE SBRACES . . . . . . = 22.1
TOTAL WEIGHT OF THE KBRACES . . . . . . = .000E+00
TOTAL WEIGHT OF THE SEC-BRACES. . . . = 95.4

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Pnl	TYP	LOAD NO::1 B L(No)		LOAD NO::2 B L (No)		LOAD NO::3 B L (No)	
		Comprsn	Tension	Comprsn	Tension	Comprsn	Tension
1	COL	.402	.000	2.390	-2.388	4.077	-4.072
2	COL	.590	.000	7.015	-7.013	11.945	-11.931
3	COL	1.127	.000	17.353	-17.351	29.507	-29.492
4	COL	2.413	.000	32.173	-32.172	54.673	-54.666
5	COL	3.461	.000	46.237	-46.232	78.532	-78.527
6	COL	4.682	.000	62.979	-62.982	106.945	-106.948
7	COL	6.147	.000	82.310	-82.312	139.746	-139.741
8	COL	7.579	.000	103.260	-103.265	175.298	-175.295
9	COL	9.383	.000	126.927	-126.929	215.455	-215.450
10	COL	11.141	.000	149.938	-149.942	254.500	-254.496
11	COL	13.116	.000	162.548	-162.556	275.898	-275.892
12	COL	15.443	.000	189.496	-189.506	321.618	-321.616
13	COL	17.915	.000	218.592	-218.600	370.989	-370.983
14	COL	20.654	.000	250.632	-250.638	425.347	-425.344
15	COL	23.699	.000	285.514	-285.522	484.530	-484.528
16	COL	27.214	.000	323.157	-323.170	548.402	-548.398
17	COL	31.485	.000	363.009	-363.013	616.025	-616.019
18	COL	36.435	.000	407.499	-407.510	691.519	-691.515
19	COL	41.855	.000	454.265	-454.275	770.872	-770.873
20	COL	47.798	.000	503.411	-503.420	854.262	-854.259
21	COL	54.272	.000	554.900	-554.909	941.631	-941.633
22	COL	61.513	.000	609.167	-609.179	1033.717	-1033.714
23	COL	70.274	.000	665.519	-665.522	1129.333	-1129.327
24	COL	81.106	.000	742.023	-742.029	1259.149	-1259.143
25	COL	92.880	.000	821.272	-821.280	1393.623	-1393.619
26	COL	105.959	.000	903.546	-903.553	1533.227	-1533.225
27	COL	119.886	.000	989.177	-989.187	1678.531	-1678.529
28	COL	135.201	.000	1076.014	-1076.018	1825.877	-1825.869
29	COL	155.349	.000	1165.390	-1165.393	1977.531	-1977.521
1	XBRC	.000	-.067	1.674	-1.674	2.149	-2.139
2	XBRC	.083	.000	4.997	-5.005	5.066	-5.076
3	XBRC	.189	.000	6.222	-6.225	6.485	-6.486
4	XBRC	.059	.000	7.494	-7.493	6.866	-6.867
5	XBRC	.080	.000	8.964	-8.966	7.808	-7.808
6	XBRC	.087	.000	10.429	-10.428	8.924	-8.924
7	XBRC	.055	.000	12.850	-12.851	11.131	-11.134
8	XBRC	.109	.000	14.748	-14.748	12.902	-12.901
9	XBRC	.037	.000	16.488	-16.489	14.496	-14.497
10	XBRC	.132	.000	18.196	-18.197	16.032	-16.035
11	XBRC	.279	.000	31.555	-31.555	26.799	-26.805
12	XBRC	.308	.000	35.081	-35.082	29.792	-29.794
13	XBRC	.365	.000	39.750	-39.752	33.778	-33.776
14	XBRC	.421	.000	44.602	-44.600	37.901	-37.900
15	XBRC	.510	.000	49.609	-49.608	42.162	-42.163

Pnl TYP	LOAD NO::1 B L(No) Comprsn	Tension	LOAD NO::2 B L (No) Comprsn	Tension	LOAD NO::3 B L (No) Comprsn	Tension
16 XBRC	.611	.000	54.224	-54.223	46.055	-46.058
17 XBRC	.665	.000	60.708	-60.708	51.591	-51.592
18 XBRC	.847	.000	65.851	-65.851	55.952	-55.952
19 XBRC	.968	.000	71.365	-71.366	60.624	-60.627
20 XBRC	1.052	.000	77.142	-77.142	65.541	-65.543
21 XBRC	1.258	.000	83.795	-83.795	71.164	-71.167
22 XBRC	1.363	.000	89.739	-89.740	76.250	-76.250
23 XBRC	1.595	.000	109.171	-109.171	92.769	-92.769
24 XBRC	1.730	.000	116.796	-116.796	99.211	-99.211
25 XBRC	2.146	.000	125.117	-125.117	106.322	-106.320
26 XBRC	2.340	.000	133.987	-133.987	113.788	-113.785
27 XBRC	2.524	.000	140.339	-140.339	119.173	-119.170
28 XBRC	2.964	.000	148.794	-148.794	126.323	-126.320
29 XBRC	2.945	.000	187.233	-187.233	158.922	-158.920
1 TRAN	.019	.000	.246	-.246	.203	-.227
11 TRAN	.010	.000	16.527	-16.535	14.547	-14.557
12 TRAN	.000	-.013	19.678	-19.676	16.703	-16.707
13 TRAN	.000	-.036	23.635	-23.635	20.086	-20.078
14 TRAN	.000	-.065	27.896	-27.893	23.699	-23.699
15 TRAN	.000	-.094	32.439	-32.436	27.557	-27.549
16 TRAN	.000	-.139	36.852	-36.854	31.314	-31.312
17 TRAN	.000	-.182	41.430	-41.432	35.242	-35.234
18 TRAN	.000	-.176	46.480	-46.484	39.479	-39.477
19 TRAN	.000	-.299	51.875	-51.875	44.074	-44.070
20 TRAN	.000	-.375	57.549	-57.549	48.875	-48.873
21 TRAN	.000	-.427	63.990	-63.992	54.360	-54.353
22 TRAN	.000	-.561	69.950	-69.948	59.418	-59.419
23 TRAN	.000	-.546	78.120	-78.119	66.430	-66.429
24 TRAN	.000	-.533	85.957	-85.958	73.025	-73.025
25 TRAN	.000	-.612	94.388	-94.389	80.162	-80.162
26 TRAN	.000	-.981	103.323	-103.324	88.444	-88.445
27 TRAN	.000	-.933	110.386	-110.386	94.327	-94.325
28 TRAN	.000	-1.126	119.121	-119.122	101.124	-101.125
29 TRAN	.000	-1.281	127.327	-127.327	108.451	-108.453
11 SBRC	.021	.000	.007	-.010	.012	-.012
12 SBRC	.022	.000	.007	-.007	.011	-.011
13 SBRC	.026	.000	.013	-.013	.022	-.020
14 SBRC	.029	.000	.018	-.015	.028	-.025
15 SBRC	.034	.000	.015	-.014	.022	-.025
16 SBRC	.039	.000	.017	-.017	.027	-.030
17 SBRC	.042	.000	.031	-.031	.053	-.054
18 SBRC	.053	.000	.020	-.020	.034	-.032
19 SBRC	.058	.000	.022	-.022	.036	-.035
20 SBRC	.061	.000	.035	-.035	.059	-.059

Pnl	TYP	LOAD NO::1 B L(No)		LOAD NO::2 B L (No)		LOAD NO::3 B L (No)	
		Comprsn	Tension	Comprsn	Tension	Comprsn	Tension
21	SBRC	.071	.000	.022	-.023	.038	-.037
22	SBRC	.074	.000	.050	-.050	.085	-.084
23	SBRC	.098	.000	.047	-.047	.079	-.079
24	SBRC	.103	.000	.046	-.046	.076	-.077
25	SBRC	.123	.000	.061	-.061	.103	-.103
26	SBRC	.129	.000	.047	-.047	.079	-.079
27	SBRC	.137	.000	.047	-.047	.081	-.080
28	SBRC	.156	.000	.058	-.058	.098	-.098
29	SBRC	.189	.000	.025	-.025	.043	-.043

PANEL MEMBER FORCES INFORMATION

Pnl	Typ	Load Case No::1 BL1*1.0+BL2*1.0+BL3* .0 Comprsn	Tension	Load Case No::2 BL1*1.0+BL2* .0+BL3*1.0 Comprsn	Tension	Load Case No::3 BL1* .0+BL2* .0+BL3* .0 Comprsn	Tension
1	COL	2.792	-1.986	4.478	-3.670	.000	.000
2	COL	7.605	-6.423	12.535	-11.341	.000	.000
3	COL	18.480	-16.224	30.634	-28.365	.000	.000
4	COL	34.586	-29.760	57.085	-52.254	.000	.000
5	COL	49.698	-42.771	81.994	-75.065	.000	.000
6	COL	67.661	-58.300	111.627	-102.266	.000	.000
7	COL	88.457	-76.165	145.893	-133.594	.000	.000
8	COL	110.839	-95.686	182.877	-167.716	.000	.000
9	COL	136.310	-117.545	224.838	-206.067	.000	.000
10	COL	161.079	-138.801	265.641	-243.355	.000	.000
11	COL	175.663	-149.440	289.013	-262.776	.000	.000
12	COL	204.938	-174.063	337.060	-306.173	.000	.000
13	COL	236.506	-200.685	388.903	-353.068	.000	.000
14	COL	271.285	-229.984	446.001	-404.690	.000	.000
15	COL	309.213	-261.823	508.229	-460.829	.000	.000
16	COL	350.370	-295.956	575.614	-521.185	.000	.000
17	COL	394.493	-331.530	647.508	-584.536	.000	.000
18	COL	443.933	-371.076	727.953	-655.081	.000	.000
19	COL	496.118	-412.421	812.725	-729.019	.000	.000
20	COL	551.208	-455.623	902.059	-806.462	.000	.000
21	COL	609.170	-500.638	995.901	-887.362	.000	.000
22	COL	670.678	-547.666	1095.228	-972.202	.000	.000
23	COL	735.792	-595.249	1199.606	-1059.054	.000	.000
24	COL	823.128	-660.924	1340.254	-1178.038	.000	.000
25	COL	914.151	-728.401	1486.502	-1300.740	.000	.000
26	COL	1009.504	-797.594	1639.185	-1427.266	.000	.000
27	COL	1109.062	-869.302	1798.416	-1558.645	.000	.000
28	COL	1211.214	-940.819	1961.077	-1690.670	.000	.000
29	COL	1320.737	-1010.046	2132.879	-1822.174	.000	.000
1	XBRC	1.607	-1.741	2.082	-2.206	.000	.000
2	XBRC	5.080	-4.922	5.149	-4.993	.000	.000
3	XBRC	6.412	-6.036	6.674	-6.297	.000	.000
4	XBRC	7.553	-7.434	6.925	-6.808	.000	.000
5	XBRC	9.044	-8.886	7.888	-7.728	.000	.000
6	XBRC	10.517	-10.341	9.012	-8.836	.000	.000
7	XBRC	12.904	-12.796	11.185	-11.079	.000	.000
8	XBRC	14.856	-14.639	13.010	-12.792	.000	.000
9	XBRC	16.524	-16.452	14.532	-14.460	.000	.000
10	XBRC	18.328	-18.065	16.164	-15.902	.000	.000
11	XBRC	31.833	-31.277	27.078	-26.526	.000	.000
12	XBRC	35.389	-34.774	30.100	-29.486	.000	.000
13	XBRC	40.115	-39.387	34.143	-33.411	.000	.000
14	XBRC	45.022	-44.180	38.322	-37.479	.000	.000
15	XBRC	50.118	-49.098	42.671	-41.653	.000	.000

PANEL MEMBER FORCES INFORMATION

?nl	Typ	Load Case No::1		Load Case No::2		Load Case No::3	
		BL1*1.0+BL2*1.0+BL3* .0		BL1*1.0+BL2* .0+BL3*1.0		BL1* .0+BL2* .0+BL3* .0	
		Comprsn	Tension	Comprsn	Tension	Comprsn	Tension
16	XBRC	54.835	-53.612	46.666	-45.448	.000	.000
17	XBRC	61.372	-60.043	52.256	-50.927	.000	.000
18	XBRC	66.698	-65.004	56.799	-55.105	.000	.000
19	XBRC	72.333	-70.398	61.591	-59.659	.000	.000
20	XBRC	78.194	-76.091	66.592	-64.492	.000	.000
21	XBRC	85.053	-82.538	72.422	-69.909	.000	.000
22	XBRC	91.102	-88.377	77.613	-74.887	.000	.000
23	XBRC	110.766	-107.576	94.364	-91.174	.000	.000
24	XBRC	118.526	-115.066	100.941	-97.481	.000	.000
25	XBRC	127.263	-122.972	108.468	-104.175	.000	.000
26	XBRC	136.327	-131.646	116.128	-111.445	.000	.000
27	XBRC	142.863	-137.816	121.697	-116.647	.000	.000
28	XBRC	151.758	-145.831	129.287	-123.357	.000	.000
29	XBRC	190.178	-184.288	161.868	-155.975	.000	.000
1	TRAN	.265	-.226	.223	-.207	.000	.000
11	TRAN	16.537	-16.525	14.557	-14.547	.000	.000
12	TRAN	19.664	-19.689	16.690	-16.720	.000	.000
13	TRAN	23.599	-23.671	20.050	-20.114	.000	.000
14	TRAN	27.832	-27.957	23.634	-23.764	.000	.000
15	TRAN	32.345	-32.530	27.463	-27.643	.000	.000
16	TRAN	36.713	-36.992	31.176	-31.451	.000	.000
17	TRAN	41.248	-41.613	35.061	-35.416	.000	.000
18	TRAN	46.304	-46.661	39.302	-39.653	.000	.000
19	TRAN	51.576	-52.174	43.776	-44.369	.000	.000
20	TRAN	57.174	-57.923	48.501	-49.248	.000	.000
21	TRAN	63.564	-64.419	53.934	-54.779	.000	.000
22	TRAN	69.389	-70.510	58.857	-59.980	.000	.000
23	TRAN	77.575	-78.665	65.884	-66.974	.000	.000
24	TRAN	85.424	-86.491	72.492	-73.558	.000	.000
25	TRAN	93.776	-95.001	79.550	-80.774	.000	.000
26	TRAN	102.342	-104.305	87.464	-89.426	.000	.000
27	TRAN	109.454	-111.319	93.394	-95.257	.000	.000
28	TRAN	117.995	-120.248	99.998	-102.251	.000	.000
29	TRAN	126.046	-128.608	107.170	-109.733	.000	.000
11	SBRC	.028	.000	.033	.000	.000	.000
12	SBRC	.029	.000	.033	.000	.000	.000
13	SBRC	.039	.000	.048	.000	.000	.000
14	SBRC	.047	.000	.057	.000	.000	.000
15	SBRC	.048	.000	.056	.000	.000	.000
16	SBRC	.056	.000	.066	.000	.000	.000
17	SBRC	.073	.000	.095	-.012	.000	.000
18	SBRC	.073	.000	.087	.000	.000	.000
19	SBRC	.080	.000	.094	.000	.000	.000
20	SBRC	.096	.000	.120	.000	.000	.000

PANEL MEMBER FORCES INFORMATION

Pnl	Typ	Load Case No::1 BL1*1.0+BL2*1.0+BL3* .0 Comprsn	Tension	Load Case No::2 BL1*1.0+BL2* .0+BL3*1.0 Comprsn	Tension	Load Case No::3 BL1* .0+BL2* .0+BL3* .0 Comprsn	Tension
21	SBRC	.093	.000	.109	.000	.000	.000
22	SBRC	.124	.000	.159	-.009	.000	.000
23	SBRC	.145	.000	.177	.000	.000	.000
24	SBRC	.148	.000	.179	.000	.000	.000
25	SBRC	.184	.000	.226	.000	.000	.000
26	SBRC	.175	.000	.208	.000	.000	.000
27	SBRC	.184	.000	.217	.000	.000	.000
28	SBRC	.214	.000	.254	.000	.000	.000
29	SBRC	.214	.000	.232	.000	.000	.000

PANEL DESIGN INFORMATION

Pnl	Ptyp	Mtyp	Eflnt	S I Z E	mm	mm	mm	Arrn	No.	Comprsn	Strto	Lcom	Tnsion	Strto	Lcom
1	XB	COL	.90	ISA	80.	80.	6.	SNGL	1.	4.5	.0	5	-4.1	.0	3
2	XX	COL	.90	ISA	80.	80.	6.	SNGL	1.	13.	.1	5	-12.	.1	3
3	XX	COL	1.54	ISA	100.	100.	10.	SNGL	1.	31.	.2	5	-29.	.1	3
4	XX	COL	1.46	ISA	100.	100.	10.	SNGL	1.	57.	.3	5	-55.	.3	3
5	XX	COL	1.41	ISA	100.	100.	10.	SNGL	1.	82.	.4	5	-79.	.4	3
6	XX	COL	1.39	ISA	130.	130.	10.	SNGL	1.	.11E+03	.3	5	-.11E+03	.4	3
7	XX	COL	1.47	ISA	130.	130.	10.	SNGL	1.	.15E+03	.5	5	-.14E+03	.5	3
8	XX	COL	1.46	ISA	130.	130.	10.	SNGL	1.	.18E+03	.6	5	-.18E+03	.6	3
9	XX	COL	1.45	ISA	110.	110.	16.	SNGL	1.	.22E+03	.6	5	-.22E+03	.6	3
10	XX	COL	1.44	ISA	110.	110.	16.	SNGL	1.	.27E+03	.7	5	-.25E+03	.7	3
11	KK	COL	.97	ISA	110.	110.	16.	SNGL	1.	.29E+03	.6	5	-.28E+03	.8	3
12	KK	COL	.97	ISA	110.	110.	8.	STAR	2.	.34E+03	.7	5	-.32E+03	.8	3
13	KK	COL	.97	ISA	110.	110.	8.	STAR	2.	.39E+03	.8	5	-.37E+03	.9	3
14	KK	COL	.97	ISA	130.	130.	8.	STAR	2.	.45E+03	.7	5	-.43E+03	.8	3
15	KK	COL	.97	ISA	130.	130.	8.	STAR	2.	.51E+03	.8	5	-.48E+03	.9	3
16	KK	COL	.97	ISA	200.	200.	15.	SNGL	1.	.58E+03	.7	5	-.55E+03	.8	3
17	KK	COL	.77	ISA	200.	200.	15.	SNGL	1.	.65E+03	.8	5	-.62E+03	.9	3
18	KK	COL	.77	ISA	110.	110.	16.	STAR	2.	.73E+03	.7	5	-.69E+03	.8	3
19	KK	COL	.77	ISA	110.	110.	16.	STAR	2.	.81E+03	.8	5	-.77E+03	.9	3
20	KK	COL	.77	ISA	130.	130.	16.	STAR	2.	.90E+03	.8	5	-.85E+03	.8	3
21	KK	COL	.77	ISA	130.	130.	16.	STAR	2.	.10E+04	.9	5	-.94E+03	.9	3
22	KK	COL	.77	ISA	130.	130.	10.	STAR	4.	.11E+04	.7	5	-.10E+04	.7	3
23	KK	COL	.80	ISA	130.	130.	10.	STAR	4.	.12E+04	.8	5	-.11E+04	.8	3
24	KK	COL	.80	ISA	130.	130.	12.	STAR	4.	.13E+04	.8	5	-.13E+04	.7	3
25	KK	COL	.80	ISA	130.	130.	12.	STAR	4.	.15E+04	.8	5	-.14E+04	.8	3
26	KK	COL	.80	ISA	150.	150.	12.	STAR	4.	.16E+04	.8	5	-.15E+04	.8	3
27	KK	COL	.80	ISA	150.	150.	12.	STAR	4.	.18E+04	.9	5	-.17E+04	.8	3
28	KK	COL	.80	ISA	150.	150.	16.	STAR	4.	.20E+04	.7	5	-.18E+04	.7	3
29	KK	COL	.88	ISA	150.	150.	16.	STAR	4.	.21E+04	.8	5	-.20E+04	.7	3
1	XB	XBRC	.95	ISA	50.	50.	6.	SNGL	1.	2.1	.0	3	-2.2	.0	5
2	XX	XBRC	.95	ISA	50.	50.	6.	SNGL	1.	5.1	.1	5	-5.1	.1	3
3	XX	XBRC	1.60	ISA	50.	50.	6.	SNGL	1.	6.7	.3	5	-6.5	.1	3
4	XX	XBRC	1.58	ISA	50.	50.	6.	SNGL	1.	7.6	.3	4	-7.5	.1	2
5	XX	XBRC	1.60	ISA	50.	50.	6.	SNGL	1.	9.0	.4	4	-9.0	.1	2
6	XX	XBRC	1.66	ISA	50.	50.	6.	SNGL	1.	11.	.5	4	-10.	.2	2
7	XX	XBRC	1.83	ISA	50.	50.	6.	SNGL	1.	13.	.7	4	-13.	.2	2
8	XX	XBRC	1.93	ISA	50.	50.	6.	SNGL	1.	15.	.9	4	-15.	.2	2
9	XX	XBRC	2.03	ISA	50.	50.	6.	SNGL	1.	17.	.5	4	-16.	.2	2
10	XX	XBRC	2.15	ISA	50.	50.	6.	SNGL	1.	18.	.6	4	-18.	.2	2
11	KK	XBRC	1.13	ISA	50.	50.	6.	SNGL	1.	32.	.8	4	-32.	.7	2
12	KK	XBRC	1.17	ISA	50.	50.	6.	SNGL	1.	35.	.9	4	-35.	.8	2
13	KK	XBRC	1.20	ISA	50.	50.	6.	SNGL	1.	40.	.6	4	-40.	.6	2
14	KK	XBRC	1.24	ISA	50.	50.	6.	SNGL	1.	45.	.7	4	-45.	.7	2
15	KK	XBRC	1.28	ISA	50.	50.	6.	SNGL	1.	50.	.8	4	-50.	.7	2

PANEL DESIGN INFORMATION

Pnl	Ptyp	Mtyp	Eflnt	S I Z E	mm	mm	mm	Arrn	No.	Comprsn	Strto	Lcom	Tnsion	Strto	Lcom
16	KK	XBRC	1.32	ISA	65.	65.	6.	SNGL	1.	55.	.9	4	-54.	.8	2
17	KK	XBRC	1.05	ISA	65.	65.	6.	SNGL	1.	61.	.8	4	-61.	.9	2
18	KK	XBRC	1.09	ISA	65.	65.	6.	SNGL	1.	67.	.7	4	-66.	.8	2
19	KK	XBRC	1.12	ISA	75.	75.	6.	SNGL	1.	72.	.8	4	-71.	.9	2
20	KK	XBRC	1.16	ISA	75.	75.	6.	SNGL	1.	78.	.9	4	-77.	.9	2
21	KK	XBRC	1.19	ISA	80.	80.	6.	SNGL	1.	85.	.9	4	-84.	.9	2
22	KK	XBRC	1.23	ISA	80.	80.	6.	SNGL	1.	91.	.8	4	-90.	.8	2
23	KK	XBRC	1.14	ISA	100.	100.	6.	SNGL	1.	.11E+03	.8	4	-.11E+03	.9	2
24	KK	XBRC	1.18	ISA	100.	100.	6.	SNGL	1.	.12E+03	.7	4	-.12E+03	.8	2
25	KK	XBRC	1.21	ISA	90.	90.	8.	SNGL	1.	.13E+03	.8	4	-.13E+03	.9	2
26	KK	XBRC	1.25	ISA	90.	90.	8.	SNGL	1.	.14E+03	.9	4	-.13E+03	.9	2
27	KK	XBRC	1.29	ISA	90.	90.	8.	SNGL	1.	.14E+03	.8	4	-.14E+03	.8	2
28	KK	XBRC	1.33	ISA	90.	90.	8.	SNGL	1.	.15E+03	.8	4	-.15E+03	.8	2
29	KK	XBRC	1.20	ISA	100.	100.	10.	SNGL	1.	.19E+03	.8	4	-.19E+03	.9	2
1	XB	TRAN	.68	ISA	50.	50.	6.	SNGL	1.	.27	.0	4	-.25	.0	2
11	KK	TRAN	1.88	ISA	50.	50.	6.	SNGL	1.	17.	.5	4	-17.	.2	2
12	KK	TRAN	2.10	ISA	50.	50.	6.	SNGL	1.	20.	.7	2	-20.	.2	4
13	KK	TRAN	2.31	ISA	65.	65.	6.	SNGL	1.	24.	.9	2	-24.	.3	4
14	KK	TRAN	2.52	ISA	75.	75.	6.	SNGL	1.	28.	.9	2	-28.	.3	4
15	KK	TRAN	2.73	ISA	75.	75.	8.	SNGL	1.	32.	.9	2	-33.	.3	4
16	KK	TRAN	2.95	ISA	75.	75.	8.	SNGL	1.	37.	.7	2	-37.	.3	4
17	KK	TRAN	3.16	ISA	100.	100.	6.	SNGL	1.	41.	.9	2	-42.	.3	4
18	KK	TRAN	3.38	ISA	90.	90.	10.	SNGL	1.	46.	.9	2	-47.	.3	4
19	KK	TRAN	3.61	ISA	90.	90.	10.	SNGL	1.	52.	.8	2	-52.	.3	4
20	KK	TRAN	3.83	ISA	110.	110.	8.	SNGL	1.	58.	.9	2	-58.	.3	4
21	KK	TRAN	4.06	ISA	90.	90.	12.	SNGL	1.	64.	.7	2	-64.	.3	4
22	KK	TRAN	4.28	ISA	130.	130.	8.	SNGL	1.	70.	.9	2	-71.	.3	4
23	KK	TRAN	4.51	ISA	130.	130.	10.	SNGL	1.	78.	.9	2	-79.	.3	4
24	KK	TRAN	4.80	ISA	130.	130.	10.	SNGL	1.	86.	.7	2	-86.	.3	4
25	KK	TRAN	5.10	ISA	150.	150.	10.	SNGL	1.	94.	.9	2	-95.	.3	4
26	KK	TRAN	5.39	ISA	130.	130.	12.	SNGL	1.	.10E+03	.7	2	-.10E+03	.3	4
27	KK	TRAN	5.68	ISA	130.	130.	12.	SNGL	1.	.11E+03	.8	2	-.11E+03	.3	4
28	KK	TRAN	5.97	ISA	100.	100.	8.	STAR	2.	.12E+03	.9	2	-.12E+03	.3	4
29	KK	TRAN	6.26	ISA	110.	110.	16.	SNGL	1.	.13E+03	.8	2	-.13E+03	.3	4
11	KK	SBRC	2.66	ISA	50.	50.	6.	SNGL	1.	.33E-01	.0	5	-.12E-01	.0	3
12	KK	SBRC	2.96	ISA	50.	50.	6.	SNGL	1.	.33E-01	.0	5	-.11E-01	.0	3
13	KK	SBRC	3.26	ISA	50.	50.	6.	SNGL	1.	.48E-01	.0	5	-.20E-01	.0	3
14	KK	SBRC	3.56	ISA	50.	50.	6.	SNGL	1.	.57E-01	.0	5	-.25E-01	.0	3
	KK	SBRC	3.86	ISA	50.	50.	6.	SNGL	1.	.56E-01	.0	5	-.25E-01	.0	3
	KK	SBRC	4.17	ISA	50.	50.	6.	SNGL	1.	.66E-01	.0	5	-.30E-01	.0	3
	KK	SBRC	4.47	ISA	50.	50.	6.	SNGL	1.	.95E-01	.0	5	-.54E-01	.0	3
	KK	SBRC	4.78	ISA	50.	50.	6.	SNGL	1.	.87E-01	.0	5	-.32E-01	.0	3
	KK	SBRC	5.10	ISA	50.	50.	6.	SNGL	1.	.94E-01	.0	5	-.35E-01	.0	3
	KK	SBRC	5.42	ISA	50.	50.	6.	SNGL	1.	.12	.1	5	-.59E-01	.0	3

PANEL DESIGN INFORMATION

Pnl	Ptyp	Mtyp	Eflnt	S I Z E mm		mm	mm	Arrn	No.	Comprsn	Strto	Lcom	Tnsion	Strto	Lcom
21	KK	SBRC	5.74	ISA	50.	50.	6.	SNGL	1.	.11	.1	5	-.37E-01	.0	3
22	KK	SBRC	6.06	ISA	50.	50.	6.	SNGL	1.	.16	.1	5	-.84E-01	.0	3
23	KK	SBRC	6.38	ISA	50.	50.	6.	SNGL	1.	.18	.1	5	-.79E-01	.0	3
24	KK	SBRC	6.79	ISA	50.	50.	6.	SNGL	1.	.18	.1	5	-.77E-01	.0	3
25	KK	SBRC	7.21	ISA	50.	50.	6.	SNGL	1.	.23	.2	5	-.10	.0	3
26	KK	SBRC	7.62	ISA	50.	50.	6.	SNGL	1.	.21	.2	5	-.79E-01	.0	3
27	KK	SBRC	8.03	ISA	50.	50.	6.	SNGL	1.	.22	.2	5	-.80E-01	.0	3
28	KK	SBRC	8.44	ISA	50.	50.	6.	SNGL	1.	.25	.3	5	-.98E-01	.0	3
29	KK	SBRC	8.86	ISA	50.	50.	6.	SNGL	1.	.23	.3	5	-.43E-01	.0	3